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AN X-RAY AND OPTICAL INVESTIGATION OF THE SERPENTINE MINERALS

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Abstract

More than 100 specimens belonging to the serpentine group have been investigated optically and by means of *x*-rays. Essentially all of the species now classed within the serpentine group can be referred to two main divisions, each of which shows slight modifications in the intensities of certain lines. The first division, which is referred to as the mineral serpentine, consists of varieties whose patterns are similar in atomic spacing to that of serpentine, best represented by patterns of chrysotile. The name chrysotile is reserved for serpentine occurring in veins and consisting of flexible fibers. The second division, which is referred to as the mineral antigorite, consists of varieties whose patterns are similar in atomic spacing to that of antigorite, from Antigorio valley, Piedmont.

Fragments from the specimens of each division have been examined by the immersion method and their optical properties noted. Nearly all of the specimens have been studied in thin section. The fundamental structures of both divisions appear to be fibrous. From the *x*-ray and optical studies it appears that the matrix of chrysotile is serpentine and not antigorite as thought by some authors.

General comparisons have been made between chemical analyses compiled from the literature. Based on the results of the *x*-ray and optical studies and the chemical discussion it is proposed to drop the names schweizerite, metaxite, pyroidesine, marmolite, retinalite, thermophyllite, bastite and vorhauserite as distinct mineral species in favor of the one term serpentine. Likewise it is proposed to drop the names picrosmine, picrolite, williamsite, bowenite, porcellophite, and baltimorite for the term antigorite. The term serpentinite is suggested for rocks composed of serpentine or antigorite or a mixture of both.

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Introduction

Numerous varieties of serpentine have been described and given distinct mineral names. These names have been given because of slight variations in physical properties or chemical composition from those ordinarily recognized for common serpentine. Recent studies indicate that the mineralogy of the serpentine group is a proper subject for revision, particularly in view of the existence of optical and x-ray technique not available at the time the original descriptions of the so called serpentine minerals were made. Such a study has shown that many of the varieties of serpentine, which have been given specific mineral names, have similar interplanar spacings and optical properties. It is believed that, on the basis of this study, most of the names can be eliminated as distinct mineral species and essentially all the varieties now classed within the serpentine group can be referred to two main divisions. X-ray patterns of each division exhibit slight modifications in the intensities of certain lines, but the essential patterns are consistent throughout the groups.

Acknowledgments

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The study has been aided by a grant from the Kemp Fellowship Fund and the liberal use of specimens from the Egleston Mineralogical Collection of Columbia University. Dr. W. F. Foshag of the United States National Museum has also cooperated in furnishing specimens for study. Dr. Clarence S. Ross of the U. S. Geological Survey has supplied specimens of saponite for comparison as well as certain types of serpentine.

The Nomenclature of the Serpentine Group

Precious and common serpentine were known to the ancients but none of the specific varieties were described until the beginning of the 19th century. Some 27 minerals have been listed, either definitely or

tentatively, as belonging to the serpentine group. The list could be expanded, in a few instances, by including miscellaneous but only partly substantiated names. The varieties listed below are given in the order of their original appearance in various publications.

Serpentine. Discordides; *Materia Medica.* About **50 A.D.**

Bastite. Talkart v. Trebra, *Erfahr. Inn. Gebirge,* p. 97, **1785**. Originally described with other minerals showing schillerization under the name of schiller-spar.
Haidinger, Wm., *Handb. der Mineralogie,* p. 523, **1845**.

Picrolite. Hausmann, J., *Moll's Efemeriden der Berg und Huttenkunde,* vol. **4,** p. 401, 1808.

Marmolite. Nuttall, I., Observations on the serpentine rocks of Hoboken, in New Jersey and on the minerals which they contain: *Am. Jour. Sci.* vol. **4,** p. 19, 1822.

Nephrite. (Bowenite of Dana). Bowen, G. T., Analysis of a variety of nephrite from Smithfield: *Am. Jour. Sci.,* vol. **5,** p. 346, 1822.

Picrosmine. Haidinger, Wm., *Treatise on Mineralogy,* by F. Mohs. Translation by Wm. Haidinger. Vol. **3,** p. 137, 1825.

Metaxite. Breithaupt, A., *Vollständige Characteristik des Mineral-Systems,* p. 113 and p. 326, **1832**.

Retinalite. Thomson, T., *Outlines of Mineralogy, Geology and Mineral Analysis,* **1,** p. 201, 1836.

Antigorite. Schweizer, E., Ueber den Antigorit ein neues Mineral von Edward Schweizer in Zurich: *Pogg's Annalen der Physic und Chemie,* vol. **49,** p. 595, 1840.

Porcellophite. *K. Vet.-Akademiens Handlingar, Stockholm.* **1840**.

Chrysotile. (Asbestos). Kobell, Fr. von, Ueber den schillernden Asbest von Reichenstein in Schlesien: *Jour. für practische Chemie,* vol. **2,** p. 297, 1834.

Baltimorite. Thomson, T., Notice on some new minerals: *Taylor's Philosophical Magazine,* 3rd series, vol. **22,** p. 191, 1843.

Schweizerite. Schweizer, E., *Jour. für practische Chemie,* vol. **32,** p. 378, 1844.

Williamsite. Shepard, C. U., On new minerals from Texas, Lancaster Co., Penn.: *Am. Jour. Sci.,* vol. **6,** p. 249, 1848.

Zermattite. Nordenskiöld, N., *Ueber das atomische-chemische Mineral-System und das Examinations System der Mineralien,* p. 132, **1848**.

Bowenite. Dana, J. D., *Mineralogy,* p. 265, **1850**.

Jenkinsite. Shepard, C. U., Two new minerals from Monroe, Orange Co.: *Am. Jour. Sci.,* series 2, vol. **13,** p. 392, 1852.

Thermophyllite. Nordenskiöld, A. E., *Beskrifning ofver de i Finland funna Mineralier,* p. 160, **1855**.

Vorhauserite. Kenngott, A., *Mineralogisher Forschungen,* p. 71, **1856**.

Pyroidesine. Shepard, C. U., *Cat. Meteorites,* **1872**.

Radiotine. Brauns, R., Der oberdevonishe Pikrit und die aus ihm hervorgegangenen Neubildungen: *Neues Jahrb. für Mineralogie, Beilage-Band* **18,** p. 314, 1904.

Fe-Antigorite. Eckermann, Harry von., *Geol. För. Förh. Stockholm,* vol. **47,** pp. 299–309, 1925.

Related Varieties

Deweylite. Emmons, E., *Manual of Mineralogy and Geology,* p. 133, **1826**.

Hydrophite. Svanberg, *Pogg's, Annalen der Physic und Chemie,* vol. **51,** p. 525, 1839.

Gymnite. Thomson, T., *Taylor's Philosophical Magazine,* 3rd series, vol. **22,** p. 191, 1843.

Genthite. Genth, *Kell & Tiedm. Monatsb.,* vol. **3,** p. 487, 1851.

Ekmannite. Igelström, L. J., *Öfv. Vet. Ak. Stockholm,* vol. **22,** p. 607, 1865.

Due to the fact that virtually all of the members of the serpentine group were described before the development of present day optical and x-ray technique, the observed physical properties and chemical compositions played the major role in the original descriptions. The megascopic nature of the specimens originally described combined with their chemical analyses have probably determined the nomenclature of serpentine as we find it today. The types of serpentine may be divided in a general way into three classes when considered from the standpoint of structure in the hand specimen.

(1) Massive. Serpentine, bowenite, retinalite, schweizerite, vorhauserite, porcellophite, williamsite and pyroidesine.
(2) Lamellar. Antigorite, marmolite and thermophyllite.
(3) Fibrous. Chrysotile, picrolite, baltimorite, metaxite, jenkinsite, and picrosmine.

Optical and x-ray studies demonstrate, however, that this classification of types is independent of the mineralogical nature of the material.

Methods of Study

Different specimens of the ordinary varieties described in the literature were selected for their apparent purity in the hand specimen. Portions of each were chosen for the x-ray and optical studies. A classification of the varieties was first made by comparison of x-ray diffraction patterns. These were secured by the standard powder method, using the $K\alpha$ series of molydenum radiation and computing the measured distances from the zero beam according to the formula $n\lambda = 2d \sin \theta$. The standard patterns used for comparison purposes and for the recorded measurements were carefully checked against sodium chloride.

The optical investigation was divided into two parts: (1) the optical properties of sized fragments of each specimen were noted by means of the oil immersion method; (2) nearly all of the specimens were examined in thin section for purity and compared for structural similarity and difference. The optical descriptions are based on the results obtained from the combined studies.

X-ray Studies

More than 100 specimens of the serpentine group and chemically related types were examined by means of x-rays. The patterns obtained from the specimens foreign to the serpentine group were used, partly, to check against lines in the serpentine patterns due to impurities and, partly, to check the likelihood of similarity to the serpentine group in interplanar spacing. Of these deweylite is included in the discussion of the serpentine group. Patterns of ekmannite, asbeferrite, sepiolite, saponite, meershaum, celadonite and common chlorite are found to be

quite different from those of the serpentine group. Weak patterns of cerolite from Frankenstein, Silesia and of garnierite from New Caledonia show a close relationship to deweylite. The patterns of celadonite from Verona indicate that the material is not a member of the serpentine group, but is perhaps related to glauconite.

The patterns of micaceous specimens labelled ekmannite from Grythyttan, Sweden, do not resemble any patterns of the serpentine or chlorite groups. This mineral is thought to be a manganiferous ferroantigorite by some authors. The *x*-ray pattern and the birefringence of the mineral indicate that it is not an antigorite although Winchell finds that it fits into his chlorite diagram very well except for its high birefringence (0.048).

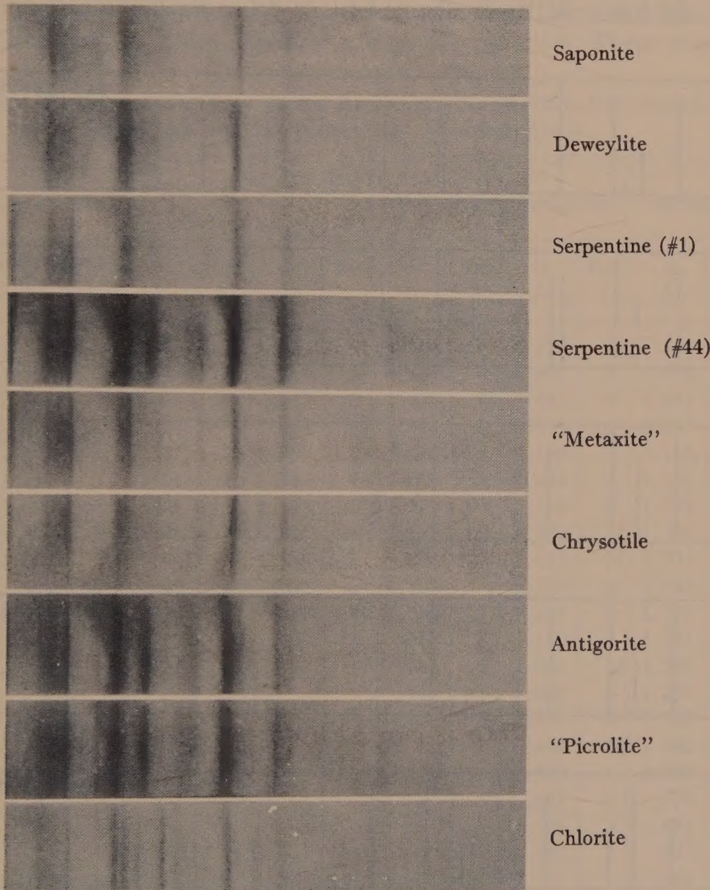


PLATE I. Showing the *x*-ray diffraction patterns of saponite, deweylite, serpentine (#1), serpentine (#44), "metaxite," chrysotile, antigorite, "picrolite" and chlorite.

A pattern of saponite has been included in the plate of x-ray patterns to show its similarity to weak patterns of deweylite.

Examination of the x-ray patterns of the minerals of serpentine indicates that the patterns can be divided into two groups, each with slight modifications in the sharpness and intensities of certain lines. The first, here considered to belong to the mineral serpentine, consists of varieties whose interplanar spacing is similar to that of chrysotile. (See Tables I, II and III). The name chrysotile, however, is reserved for serpentine

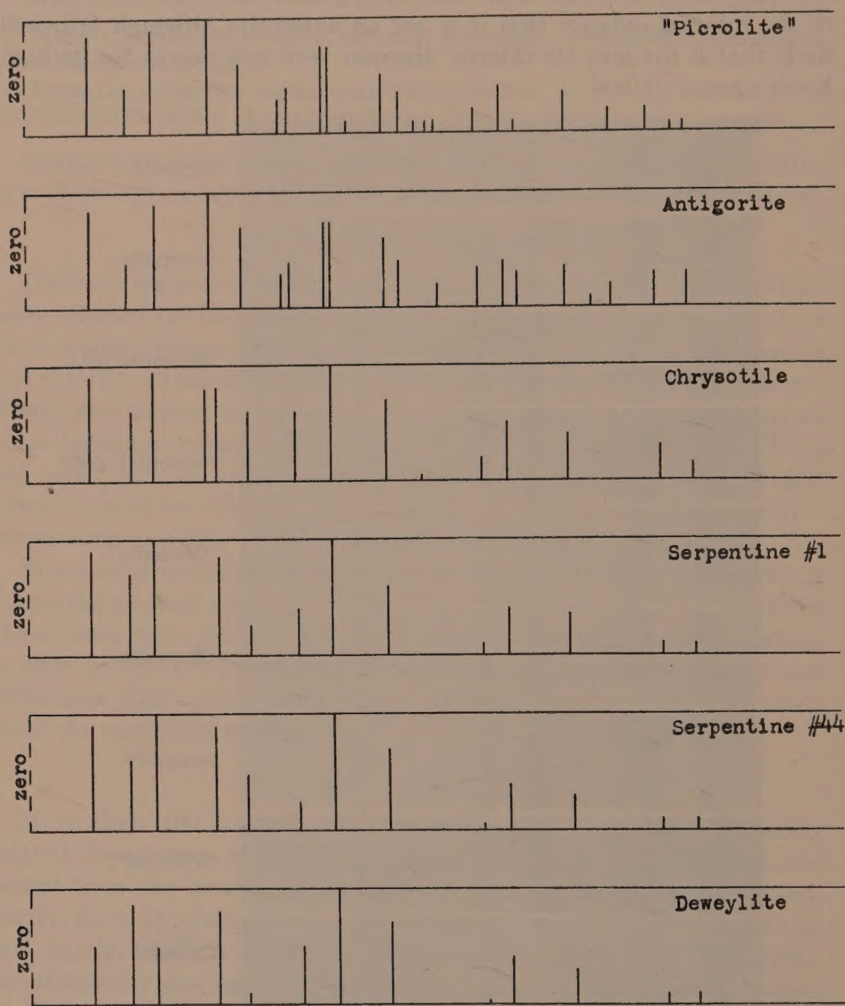


FIG. 1. Showing the relative positions and intensities of the lines for "picrolite," antigorite, chrysotile, serpentine and deweylite as measured in millimeters from the zero line

that occurs in veins and consists of flexible fibers. This conforms with its original description as a new type of asbestos. The second, here considered to belong to the mineral antigorite, includes varieties structurally similar to antigorite from the Antigorio valley, Piedmont, Italy. (See Table IV).

X-ray patterns of the mineral serpentine show three minor modifications. These consist of slight variations in the sharpness and intensities of certain lines. Many of the lines are broad and indistinct, thereby making individual measurements difficult. The background of the patterns indicates that there is a considerable amount of general scattering of the x-rays. The variations are probably due to slight chemical differences and degrees of crystallization in addition to minor variations depending on the length of exposure and the development of the x-ray film.

The lines are best developed in chrysotile patterns. These show a

Table VI. Interplanar Spacing for Deweylite, Serpentine, Chrysotile, Antigorite and "Picrolite," in Angstrom Units.

Line No.	Deweylite		Serpentine #44		Serpentine #1		Chrysotile		Antigorite		"Picrolite"	
	d Å	Est I	d Å	Est I	d Å	Est I	d Å	Est I	d Å	Est I	d Å	Est I
1	7.374	5	7.379	9	7.384	9	7.364	9	7.355	8½	7.364	8½
2	4.594	8½	4.573	6	4.604	7	4.431	6	4.668	4	4.624	4
3	3.668	5	3.656	10	3.695	10	3.658	9½	3.641	9	3.641	9
4	2.457	8	2.477	9	2.463	8½	2.571	8	2.558	10	2.513	10
5	2.127	1	2.131	5	2.098	2½	2.424	8	2.186	7	2.168	6
6	1.717	5	1.721	2½	1.724	4	2.089	6	1.845	3	1.833	3
7	1.520	10	1.527	10	1.528	10	1.729	6	1.794	4	1.774	4
8	1.306	7	1.306	7	1.306	6	1.522	10	1.583	7½	1.566	7½
9	1.040	¼	1.044	½	1.047	1	1.301	7	1.553	7½	1.534	7½
10	.990	4	.990	4	.992	4	1.187	½	1.326	6	1.448	1
11	.878	3	.877	3	.882	3½	1.039	2	1.273	4	1.311	5
12	.761	1	.762	1	.762	1	.985	5	1.160	2	1.251	3½
13	.728	1	.721	1	.727	1	.881	4	1.061	3½	1.203	1
14							.761	3	1.005	4	1.167	1
15							.727	1½	.979	3	1.145	1
16									.897	3½	1.055	2
17									.859	1	1.000	4
18									.831	2	.970	1
19									.778	3	.884	3½
20									.743	3	.833	2
21											.775	2
22											.751	1
23											.738	1

sharp doublet at 2.571 and 2.424 A.U., and fairly sharp lines throughout. (See Plate I; Fig. 1 and Table VI). The varieties included under serpentine in Table III show line 4.431 more intense, and line 2.571 A.U. less intense than the corresponding lines in the chrysotile pattern. Otherwise the patterns of Table III are identical. The nature of the variation is best shown in the patterns of metaxite (#53) and schweizerite (#38).

In the patterns of the varieties listed under Tables I and II the first line of the doublet is represented by a shaded area of variable width and intensity. It extends to the second line of the doublet which is in normal position. Certain of the remaining lines are less intense and less distinct than the corresponding lines in the chrysotile patterns. The patterns of the varieties listed under Table I vary from those listed under Table II in that the intensities of lines 2.098 and 1.724 A.U. are reversed. (See Fig. 1). This difference, although very slight, is distinctly noticeable in certain patterns. These two lines also vary slightly in the chrysotile patterns.

The above variations are not considered sufficiently significant to justify new mineral species, particularly in the absence of optical and chemical confirmation. The variations have been noted not for the purpose of dividing the group but for purposes of record. A slight intensity gradation can be traced in the patterns which seemingly parallels the corresponding change from the massive forms, listed under Tables I and II, through the brittle, splintery types of Table III to the flexible fiber, chrysotile. The modifications, presumably, are chiefly due to varying degrees in the development of crystallinity.

Antigorite is best represented by the patterns of antigorite from Antigorio valley and Traföss, Styria, and picrolite from North Carolina. The distinctive differences between the patterns of serpentine and antigorite are (1) the increase in the distance between lines 4.431 and 3.658 A.U.; (2) the disappearance of the chrysotile doublet; (3) the appearance of the antigorite doublet and (4) a slight increase in the number of lines. (See Plate I; Fig. 1 and Table VI). The varieties listed near the bottom in Table IV show lines 2.186, 1.845 and 1.794 A.U. less intense and the doublet less distinct than the corresponding lines in the type patterns. These variations are best shown in the pattern of porcellophite from Staten Island.

The patterns of several specimens of deweylite show that it has much the same interplanar spacing as the amber material from Turkey Mountain. The variation of the intensities of the first three lines of deweylite distinguishes it from serpentine. (See Plate I; Fig. 1 and Table VI).

Chemically it is closely related to serpentine, being slightly more hydrous.

A specimen of baltimorite from Lancaster Co., Pennsylvania, which was altering to a lavender colored chlorite, gave a pattern identical to one obtained from a chlorite labelled kammererite from Texas, Pennsylvania.

Identical patterns were obtained from several chlorites which included clinochlore from Chester County, Penn.; clinochlore from Pfitschthal; ripidolite from Tilly Foster; penninite from Zermatt, Valais; corundophilite from Chester, Massachusetts, and prochlorite from Cumberland, England. The patterns of thuringite from Zorm Sea, Corinthea, and kammererite from Texas, Pennsylvania, differed from each other and from the above group of chlorites. In his *x*-ray study of clinochlore and penninite Pauling[1] determined the unit cell as monoclinic, $a=5.2-3$ Å, $b=9.2-3$ Å, $c=14.3-4$ Å and the space group as C^3_{2h}.

From the study of the *x*-ray diffraction patterns of serpentine, antigorite and the chlorites, it does not appear that there is any definite structural reason for including antigorite as an end member of the chlorite series. The pattern appears to be as close to serpentine as to chlorite. The patterns show a greater difference than one would infer from the line drawings by Winchell.[2]

The *x*-ray study has shown that, fundamentally, chrysotile and serpentine are structurally the same. From the *x*-ray studies by Warren and Bragg[3] the unit cell of chrysotile was determined to be monoclinic and composed of 4 molecules of the formula $2(H_4Mg_3Si_2O_9)$; $a=14.66$ Å, $b=18.5$ Å, $c=5.33$ Å and $\beta=93°16'$. The space group is probably C^3_{2h}. Later Jansen[4] determined the identity period along the fiber axis of a chrysotile from Oberitalien to be 5.2 A.U. The mineral is monoclinic with $a=6.85$ Å, $b=5.16$ Å and $c=13.38$ Å. Recently Syromyatnikov[5] has described a new structural modification of chrysotile which he has called "Ishkyldite." Preliminary examination shows it to have an identity period along the fiber axis of 9.678 Å. This is nearly twice that usually assigned to chrysotile.

Previous Classifications Based on Optical Studies

A review of the literature on the microscopical characteristics of the serpentine group furnishes one with many confusing ideas as to just what specific mineral is meant when the words serpentine, chrysotile and antigorite are used. Apparently these terms are used interchangeably to include one or more of the minerals designated by the three names. The need of more precise knowledge concerning the minerals of ser-

pentine may be shown from a review of the following extracts from publications by various authors.

Winchell[6] has eliminated the serpentine group by including its members, with the exception of chrysotile, in the chlorite group. Chrysotile is described as usually occurring in a fibrous form with positive elongation. In the variety called asbestos the fibers are separable and flexible. It is optically positive with a small optic angle. Antigorite, which is described as an end member of the chlorite group, includes the lamellar rather than the fibrous varieties of serpentine which show good cleavage, positive elongation and a large negative optic angle. The birefringence is slightly less than that of chrysotile. Bastite is a coarse variety of antigorite, pseudomorphous after pyroxene. The optic plane is parallel to (010) for antigorite.

Rogers and *Kerr*[7] use the name chrysotile to describe the fibrous form, asbestos. The optic sign and elongation are positive. The axial angle is small. It usually occurs in veinlets in serpentine which consists largely of the mineral antigorite. The latter is described as occurring in anhedral crystals or aggregates of fibrolamellar structure. The optic sign is negative with variable axial angle. The elongation is positive and the extinction is parallel. Chrysotile is distinguished from its dimorph, antigorite, by its fine fibrous structure. Antigorite is the main constituent of serpentine, a metamorphic rock. The optic plane of antigorite is parallel to (100).

Johannsen[8] describes serpentine as being made up principally of fine fibers, thin prisms or thin laminated plates. Parallel fibers generally show positive elongation and parallel extinction. He quotes Tschermak as stating that fibrous serpentine has the axis of greater ease of vibration parallel to the fibers. The mineral may appear isotropic in felty aggregates.

Krotov[9] writes that the serpentines are mostly of a type intermediate between chrysotile and antigorite, which are regarded as one and the same mineral. Chrysotile is optically negative (or rarely positive) with 2V ranging in different specimens from 0° to 52°. The sign of elongation may be either positive or negative, even in adjacent fibers. The refringence and birefringence of the fibers diminish towards the center of the mesh structure. Antigorite is of three types; needles, laths and scales, but these grade into each other. It is usually optically negative with $2V = 14\frac{1}{2}°$ to 42°. The optic axial plane is perpendicular to the perfect cleavage. The elongation is always positive and pleochroism is absent.

Graham[10] states that in none of the varieties does serpentine exhibit well-defined optical characters when examined in thin section under the microscope, owing mainly to its imperfect crystalline character. It is always biaxial, with refractive indices and birefringence rather higher than for quartz; the fibers are optically positive, but certain platy varieties appear to be negative. . . . Most frequently the serpentine that forms along the cracks is in the form of parallel fibers, lying transverse to the crack, while that around the margins (of olivine) also appears as fibers, more or less parallel, or rather radially arranged. Where the alteration has proceeded further, the interior of the olivine crystal is replaced, still by fibers, but these usually have no particular orientation and appear rather as an irregular network. . . . Structurally, then, the difference between chrysotile and massive serpentine is one of degree and not of kind. The former name is used to denote those occurrences in which the fibers are so long as to be visible to the eye. . . . When, on the other hand, the fibers are microscopic, with no regular orientation, their aggregation has built up the substance "massive" serpentine.

Fisher[11] describes antigorite as being commonly developed from olivine, the alteration beginning along fractures and preserving the characteristic mesh structure superimposed by the network of fractures. The stated pleochroism of antigorite is accidental rather than essential and has seldom been noted by the writer. Chrysotile is the fibrous form of serpentine, with fibration normal to the enclosing walls of the thin veinlets in which it usually

occurs. It also resembles antigorite but is characterized by delicate fibers that show positive elongation.

Dolmage,[12] describing serpentine from the Marble Bay mine, states that it has either a dark green or honey yellow color in hand specimen. It is homogeneous in appearance, has a flinty fracture, a greasy luster and is noticeably translucent. Under the microscope two varieties are observed, the fibrous variety, asbestos and the platy variety, antigorite. This parallel arrangement is, however, not common, the greater portion has a platy structure and therefore, belongs to the antigorite variety.

Several classifications of serpentine and antigorite, based on petrographic studies, have been made. These classifications have been based primarily on the fibrous nature of serpentine in contrast to the flaky structure of antigorite as originally described by Schweizer and later by Hussak.[13]

Drasche[14] in his study of serpentines divided them into two classes; true serpentine and serpentine-like rocks. Both were very similar in chemical composition. The former showed the typical mesh structure of serpentine derived from olivine. The latter was both different in hand specimen and under the microscope. He described a specimen from Windisch Matrey in northern Tyrol as best representing the latter class. The groundmass consisted of a network of elongated sections of a rhombic mineral. These sections were rectilinear and sometimes so thin that they could be called needles. They showed parallel extinction and a perfect cleavage parallel to the long axis. Other sections, showing irregular boundaries were alternately birefringent and dark under crossed nicols. The mineral was biaxial. He inferred that the irregular sections were cut parallel to a cleavage, while the elongated sections were cut at right angles to a cleavage. He entertained the idea of chrysotile in a flaky form, but as it was insoluble in HCl, he decided to consider the mineral as bastite because of its association with pyroxene.

In 1905 *Bonney* and *Raisin*[15] drew the following conclusions concerning the minerals forming serpentine:

(1) That a tint and pleochroism are accidental rather than essential characteristics of the variety of the mineral serpentine named antigorite.

(2) That, if low polarization tints be regarded as an essential characteristic of antigorite, a closely associated mineral must exist, which is distinguished only by higher birefringence. If the minerals can be isolated and subjected to analysis they may prove to be distinct: but the way in which, as described in the preceding pages, they seem to graduate one into the other, leads us to believe that they are varieties of a single mineral —antigorite. Both forms usually afford straight extinction but it is occasionally oblique, though the angle is small. Thus, either the mineral is dimorphous, or its optical characters have been affected by pressure, or it is really monoclinic.

(3) That it is doubtful whether any hard-and-fast line can be drawn between the rather fibrous forms of the mineral in the ordinary serpentine-rocks and the mica like (antigorite) of certain others.

(4) That the most typical antigorite occurs when the rock has been considerably affected by pressure, but that it becomes rather less typical when the pressure has been very great (that is in the most slaty serpentines).

Tertsch[16] is able to distinguish two minerals in all of the serpentine occurrences of the Dunkelsteiner Granulitmassives. Both are finely fibrous with $n=1.54$ and the birefringence varying from .006 to .010. They are usually colorless in thin section, exceptions being colored light chrome green without recognizable pleochroism. The two minerals are distinguished by the optical character of the fiber axis. The first, which he calls gamma serpentine, is optically comparable to chrysotile. It usually shows weaker refringence and birefringence than the second, which he calls alpha serpentine. This type has negative elongation.

These two minerals occur together in two different combinations, namely; mesh and window structures. (See Figs. 2 and 3 of Tertsch, p. 188). In the mesh structure type the meshes are marked by lines of metallics. Bands of gamma serpentine, with the fiber axes normal to their length, run parallel to the lines of metallics. The enclosed field is composed of triangular sectors of alpha serpentine with the fibers oriented at right angles to the walls of the veins. Higher magnifications show a transverse parting in the alpha serpentine. Often a brownish turbidity runs parallel to the field boundaries. The birefringence of both of the minerals varies as the stage is rotated. The center of the field is almost isotropic and shows a small negative optic angle.

Serpentine with window structure shows the reverse relationship of the two minerals. Fairly regular parallelogram meshes are built by bands of alpha serpentine. The fields are composed of gamma serpentine. The fibers in both the bands and the fields are perpendicular to the length of the bands. The center of the field shows a probable uniaxial figure. Although no original mineral was found Tertsch concludes that it was olivine.

Angel and *Martiny*[17] describe a mesh structure serpentine from Kraubath as chrysotile. The meshes surround fresh olivine. The centers of the veins are sometimes isotropic, weakly anisotropic or filled with antigorite. Figure 2 shows the optical orientation of the fibers described by them.

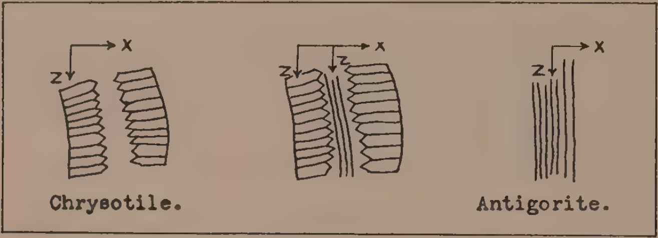


FIG. 2. Illustrating the optical orientation of the fibers of mesh structure serpentine from Kraubath. By Angel and Martiny.

Angel[18] in his study of the Stubachit serpentine made the following classification to distinguish the forms in which antigorite and fibrous serpentine occur:

EINZELFORMEN UND ZWILLINGE (after Angel)
I. Blätterserpentin (Antigorit)

$\mathfrak{a} \perp$ zur Blattfläche und Spaltung.

(A) Grobblättriger.
1. Kluftantigorit,
2. Freier Fächerantigorit,
3. Füllungs-Fächerantigorit.

(B) Feinblättriger.
1. Feinantigorit.

II. Faserserpentin.

(A) Goldfaserserpentin (Chrysotil).
$\mathfrak{c}$ = Faserachse.
1. Kluftchrysotil,
2. Rahmenchrysotil,
3. Bastitfaser,
4. Villarsitfaser.

(B) Gemeiner Faserserpentin
$\mathfrak{a}$ = Faserachse.
1. Gemeine Kluftfaser,
2. Gemeine Rahmenfaser.

Explanation of Angel's Terms.

The "Kluftantigorit" consists of coarse leaves of some length visible to the unaided eye in hand specimen.

The "Freier Fächerantigorit," which is common to the Ganoz serpentine, is composed of fan-shaped twins interlaced through one another to form an aggregate. In a single fan the orientation varies from leaf to leaf giving wavy extinction. The widths of the leaves also vary from one to another in a single fan-shaped twin. In many of the serpentines the simple fan stands out stronger than the aggregate.

"Füllungs-Fächerantigorit" at the first glance presents an hour glass figure. Closer study shows it to be a lattice structure with fairly developed sectors, whose contacts are not rectilinear but bowed or crumpled. It is composed of twinned antigorite with the leaves cut at right angles to the base. The fields are made up of roll-like, superimposed antigorite leaves. At times the fan shapes can be seen. This type of antigorite has only been observed with such clearness in the Ganoz serpentines. The difference between the preceding class and this, is that the antigorite is seen as sheafs with almost ravelled out ends in the former, while the ends of the "Füllungs-Fächerantigorit" are cut off evenly.

"Feinantigorit" accompanies the coarser, building felted masses.

The "Kluftchrysotil" is found in veins.

The "Rahmenfaser" which belongs, in part, to chrysotile and, in part, to the common type fills the spaces in lattice structures.

The "Bastitfaser" type consists of single fibers which have the form of "sphärischen Zweiecks," of moderate length and with Z parallel to the long axis. This can be regarded as similar to a crystal of chlorite that has developed along the *c*-axis resulting in a columnar to fibrous form instead of the normal platy form after (001). This conception is supported by the fact that a cleavage runs at right angles to the length of the fibers that can be coaxial with that of the antigorite cleavage. This type occurs with pyroxene.

The "Villarsitfaser" likewise deals with oriented fibers as in bastite but occurs in olivine.

Fragment Studies

Sized fragments of each of the specimens of the two groups were examined by the immersion method. All of the available optical properties were noted together with any detail that might lead to a clue that would help to differentiate the two groups optically. The color, purity, shape of fragment, elongation, optic sign, birefringence and the indices were recorded wherever possible. The indices were indeterminable in certain specimens because of a clouded condition of the fragments which destroyed the usefulness of the Becke line. The physical structure of the different varieties was much more evident in the shapes of the fragments than in the thin sections. Many of the types in both groups, whose fragments were splintery, gave no indication of their splintery nature in the thin sections.

The most important properties have been tabulated in Tables I to IV inclusive. These also include some data compiled from the study of the thin sections. In the column marked "Extinction of fragment" only the extinction of the elongated fragments is recorded. Usually, the extinction is complete in these. Larger fragments are occasionally slightly

mottled with mass extinction essentially parallel to the elongated direction of the fragment. The massive type of fragment gives aggregate to complete extinction on rotation of the stage.

Several significant features are apparent in the tabulation. Massive, lamellar and fibrous varieties in hand specimens occur in both serpentine and antigorite. The average indices for serpentine are slightly lower than those for antigorite. The general range of the indices of serpentine is, from that of balsam 1.538, to 1.570. The indices of antigorite range from 1.558 to 1.577. From these figures one may select the average limits 1.538 to 1.570 for serpentine, and 1.555 to 1.580 for antigorite. There is so little difference in the average indices of refraction between the two groups that it would be impossible to differentiate the greater number of the specimens in thin section or fragments on the basis of indices alone.

With the exception of penninite, Winchell[19] lists all of the optically negative chlorites with indices ranging from 1.580 to 1.640. These differences of indices would help to distinguish the remaining optically negative chlorites from serpentine and antigorite.

The average birefringence of serpentine in Tables I, II and III is from 0.007 to 0.008. This is from 0.002 to 0.003 greater than the average birefringence of antigorite. More optic signs, usually showing a small optic angle, were obtained in antigorite than in serpentine. A striking feature of the recorded optic signs throughout both groups is that, with three exceptions which occur in serpentine, they are all biaxial negative. Optically positive serpentines have been reported by Buerger,[20] Creveling[21] and others. The index of the mineral reported by Creveling suggests that it is deweylite rather than serpentine. It is possible that a greater percentage of optically positive varieties exist, as optic signs were not obtained for all of the specimens studied. This was due either to the fineness of fiber, the diversity of orientation of the fibers or the cloudy condition of the fragments. Where one was able to determine the optical character in fragments, the determination could usually be repeated in the thin section.

The examination of the hand specimens of the three serpentines with positive optical character shows that No. 67 is definitely brittle and fibrous to columnar. Nos. 4 and 68 are massive. Nos. 67 and 68 come from the same locality but vary somewhat in hand specimen. The fragments of all three are splintery. Nos. 4 and 68 are probably on the border line, between massive serpentine and the coarse, brittle, splintery variety. These are the only two in Tables I and II that have splintery fragments. The thin sections were cut at right angles to their elongated structure, which was determined by breaking the specimens. None show their

TABLE I. SERPENTINE

No.*	Specimen and Locality	Description	Nature of fragment	Extinction of fragment	Elongation of fragment	α	γ	$\gamma-\alpha$	Optic sign
1	Serpentine, Turkey Mountain, New Jersey	amber, massive, translucent	massive			1.546	1.550	.004	2V(−)
4	Schweizerite, Dognacsca	greenish-yellow, massive, opaque	splintery	parallel	positive	1.556	1.564	.008	2V(+) small
6	Marmolite, Hoboken, New Jersey	light green, foliated, pearly luster	massive, semi-platy			1.545	1.551	.006	2V(−) small
21	Serpentine, Globe, Arizona	light tan, massive, opaque	massive			1.548	1.556	.008	
33	Gymnite, Fleims, Tyrol	white, massive, opaque	massive			1.543	1.547	.004	
40	Marmolite, Tilly Foster mine, N.Y.	grayish-green, massive, semi-platy	massive			1.538	1.545	.007	
41	Marmolite, Chester County, Penn.	gray, massive, opaque	massive			1.551	1.559	.008	
45	Serpentine, New Jersey	medium green, massive, opaque	massive			1.552	1.559	.007	2V(−)
46	Serpentine, Gawrilowsk mine, Urals	dark green, massive, opaque	massive			1.538	1.546	.008	2V(−)
47	Serpentine, Montville, New Jersey	grayish-white, massive, opaque	massive						
49	Serpentine, Easton, Penn.	yellowish-green, massive, translucent	massive			1.546	1.554	.008	2V(−)
59	Vorhauserite, Monzoni, Tyrol	brown, massive, opaque	massive						
60	Retinalite, Perth, Canada	dark grayish-green, massive, opaque	massive						

* Refers to collection number.

TABLE I. (*Continued*)

No.*	Specimen and Locality	Description	Nature of fragment	Extinction of fragment	Elongation of fragment	α	γ	$\gamma-\alpha$	Optic sign
62	Genthrite, Colerain Township, Can.	light green, massive, conchoidal fracture	massive						
66	Retinalite, Montville, New Jersey	yellowish-tan, massive, translucent	massive			1.544	1.551	.007	
68	Serpentine, Nil Desperandum, South. Rhodesia, S. Africa	medium green, massive	splintery	parallel	positive	1.559	1.567	.008	2V(+) small
70	Marmolite, Tompkinsville, Staten Island, N.Y.	light tan, massive, opaque	massive			1.551	1.557	.006	
76	Marmolite, Chapin mine, Iron Mt., Mich.	white, brownish tinge, massive	massive			1.558	1.563	.005	
79	Serpentine, Newburyport, Mass.	dark green, massive, opaque	massive			1.554	1.561	.007	
93	Serpentine after dolomite, Tilly Foster mine, N.Y.	yellowish-white, massive, opaque	massive			1.543	1.551	.008	2V(−)
95	Serpentine after olivine, N.C.	medium green, massive, opaque	massive			1.529	1.537	.008	2V(−)
96	Serpentine after ripidolite, Tilly Foster mine, N.Y.	white, massive, opaque	massive			1.541	1.546	.005	
103	Retinalite, Greenville, Canada. U.S.N.M. R-4644	dark brown, massive, opaque	massive						
108	Mn-serpentine, Franklin, N.J.	brown, massive, translucent	massive						2V(−)

* Refers to collection number.

TABLE II. SERPENTINE

No.*	Specimen and Locality	Description	Nature of fragment	Extinction of fragment	Elongation of fragment	α	γ	$\gamma-\alpha$	Optic sign
3	Serpentine, Staten Island, N.Y.	light green, massive, opaque	massive			1.551	1.559	.008	2V(−)
10	Serpentine, Tilly Foster mine, New York	medium green, massive, pseudo-cubic	rectangular	parallel					2V(−)
12	Serpentine, Thetford, Quebec	yellowish-green, massive, translucent	massive			1.547	1.554	.007	2V(−)
17	Pyroidesine, Regla, Cuba	grayish-green, massive, opaque	massive			1.564	1.570	.006	
19	Serpentine after chrysolite, Snarum, Norway	greenish-yellow, massive, opaque	massive			1.552	1.559	.007	
20	Serpentine, Somerville, N.J.	greenish-yellow, massive, opaque	massive			1.546	1.554	.008	2V(−)
43	Marmolite, Castle Rock, Hoboken, N.J.	grayish-green, massive, opaque	massive			1.558	1.564	.006	
44	Serpentine, Turkey Mt., N.J.	yellowish-green, massive, translucent	massive			1.552	1.560	.008	2V(−)
58	Serpentine, Snarum, Norway	greenish-yellow, massive, opaque	massive			1.552	1.560	.008	
77	Retinalite, Montville, N.J.	light yellow, massive, translucent	massive			1.553	1.560	.007	2V(−)
97	Thermophyllite, Finland	gray, massive, with mica	massive						small 2V(−)
105	Bastite, Baste in Harz, Germany. U.S.N.M. R-2966	black, massive, with pyroxene	massive			1.556	1.564	.008	
109	Vorhauserite, Franklin, N.J.	brown, in veins, translucent	massive			$n=$ 1.563			2V(−)
110	Serpentine, Morrisville, Vermont	dark green, massive, opaque	massive						

* Refers to collection number.

TABLE III. CHRYSOTILE

No.*	Specimen and Locality	Description	Nature of fragment	Extinction of fragment	Elongation of fragment	α	γ	$\gamma-\alpha$	Optic sign
13	Chrysotile, Morris Co., N.J.	honey, amber, silky, $\frac{1}{2}$ in-fibers	fibrous	parallel	positive	1.544	1.551	.007	
14	Asbestos, Globe, Arizona	light tan, silky, 1 in-fibers	fibrous	parallel	positive	1.532	1.545	.013	
15	Asbestos, Staten Island, N.Y.	greenish-white, silky, $\frac{1}{2}$ in-fibers	fibrous						
16	Chrysotile, Hance mine, Arizona	light tan, silky	fibrous						
30	Chrysotile, Thetford, Quebec	dark green, $1\frac{1}{2}$ in-fibers	fibrous	parallel	positive	1.537	1.553	.016	
								Vari-able	
61	Asbestos, Gawrilowsk mine, Urals	dark green, $\frac{1}{2}$ in-fibers	fibrous						
75	Chrysotile, Montville, New Jersey	amber, silky, $\frac{1}{2}$ in-fibers	fibrous	parallel	positive	1.542	1.550	.008	
			SERPENTINE						
38	Schweizerite, Zermatt, Tyrol	dark green, massive, semi-platy	splintery	parallel	positive	1.552	1.563	.011	2V(−)
53	Metaxite, Schwarzenberg, Saxony	grayish-white, radiating brittle fiber	splintery	parallel	positive	1.552	1.560	.008	2V(−)
54	Metaxite, Schwarzenberg, Saxony	light green, splintery, semi-platy	splintery	parallel	positive	1.545	1.560	.015	2V(−)
55	Metaxite, Silesia	gray, massive, conchoidal fracture	massive, platy			1.550	1.557	.007	
64	Schweizerite, Dognacsca	chalky-white, radiating, brittle fiber	splintery in part						
67	Serpentine, Shabani mine, S. Africa	medium green, brittle fiber	splintery	parallel	positive	1.551	1.559	.008	2V(+)

* Refers to collection number.

Table IV. Antigorite

No.*	Specimen and Locality	Description	Nature of fragment	Extinction of fragment	Elongation of fragment	α	γ	$\gamma-\alpha$	Optic sign
2	Antigorite, Antigorio valley, Piedmont	grayish-green, thin lamellae	massive, platy			$\beta=$ 1.574			2V(−) small
5	Williamsite, State Line mine, Penn.	emerald green, massive, translucent	massive		positive	1.559	1.563	.004	2V(−)
7	Picrolite, North Carolina	dark green, brittle, splintery	splintery	parallel	positive	1.567	1.573	.006	2V(−)
23	"Serpentine," Manchuria. Antigorite. U.S.N.M. 94356	grayish-white, opaque, massive	massive			1.558	1.562	.004	
24	Picrolite, Buck Creek, Clay Co., N.C.	medium green, radiating brittle fiber	splintery	parallel	positive	1.562	1.567	.005	2V(−)
25	Picrolite, South Lorraine, Ont.	grayish-green, brittle fiber	splintery	parallel inclined	positive				
27	Bowenite, Smithfield, R.I.	grayish-white, greenish cast, massive	massive			1.557	1.562	.005	
28	Williamsite, Texas, Pennsylvania	grayish-white, massive, opaque	massive			1.555	1.560	.005	
29	Williamsite, State Line mine, Penn.	greenish-white, massive, translucent	massive			1.559	1.564	.005	2V(−)
36	Williamsite, Texas, Pennsylvania	dark green, massive, opaque	massive			1.563	1.568	.005	2V(−) small

* Refers to collection number.

TABLE III. CHRYSOTILE

No.*	Specimen and Locality	Description	Nature of fragment	Extinction of fragment	Elongation of fragment	α	γ	$\gamma-\alpha$	Optic sign
13	Chrysotile, Morris Co., N.J.	honey, amber, silky, ½ in-fibers	fibrous	parallel	positive	1.544	1.551	.007	
14	Asbestos, Globe, Arizona	light tan, silky, 1 in-fibers	fibrous	parallel	positive	1.532	1.545	.013	
15	Asbestos, Staten Island, N.Y.	greenish-white, silky, ½ in-fibers	fibrous						
16	Chrysotile, Hance mine, Arizona	light tan, silky	fibrous						
30	Chrysotile, Thetford, Quebec	dark green, 1½ in-fibers	fibrous	parallel	positive	1.537	1.553	.016 Variable	
61	Asbestos, Gawrilowsk mine, Urals	dark green, ½ in-fibers	fibrous						
75	Chrysotile, Montville, New Jersey	amber, silky, ½ in-fibers	fibrous	parallel	positive	1.542	1.550	.008	
			SERPENTINE						
38	Schweizerite, Zermatt, Tyrol	dark green, massive, semi-platy	splintery	parallel	positive	1.552	1.563	.011	2V(−)
53	Metaxite, Schwarzenberg, Saxony	grayish-white, radiating brittle fiber	splintery	parallel	positive	1.552	1.560	.008	2V(−)
54	Metaxite, Schwarzenberg, Saxony	light green, splintery, semi-platy	splintery	parallel	positive	1.545	1.560	.015	2V(−)
55	Metaxite, Silesia	gray, massive, conchoidal fracture	massive, platy			1.550	1.557	.007	
64	Schweizerite, Dognacsca	chalky-white, radiating, brittle fiber	splintery in part						
67	Serpentine, Shabani mine, S. Africa	medium green, brittle fiber	splintery	parallel	positive	1.551	1.559	.008	2V(+)

* Refers to collection number.

TABLE IV. ANTIGORITE

No.*	Specimen and Locality	Description	Nature of fragment	Extinction of fragment	Elongation of fragment	α	γ	$\gamma-\alpha$	Optic sign
2	Antigorite, Antigorio valley, Piedmont	grayish-green, thin lamellae	massive, platy			$\beta=$ 1.574			2V(−) small
5	Williamsite, State Line mine, Penn.	emerald green, massive, translucent	massive		positive	1.559	1.563	.004	2V(−)
7	Picrolite, North Carolina	dark green, brittle, splintery	splintery	parallel	positive	1.567	1.573	.006	2V(−)
23	"Serpentine," Manchuria. Antigorite. U.S.N.M. 94356	grayish-white, opaque, massive	massive			1.558	1.562	.004	
24	Picrolite, Buck Creek, Clay Co., N.C.	medium green, radiating brittle fiber	splintery	parallel	positive	1.562	1.567	.005	2V(−)
25	Picrolite, South Lorraine, Ont.	grayish-green, brittle fiber	splintery	parallel inclined	positive				
27	Bowenite, Smithfield, R.I.	grayish-white, greenish cast, massive	massive			1.557	1.562	.005	
28	Williamsite, Texas, Pennsylvania	grayish-white, massive, opaque	massive			1.555	1.560	.005	
29	Williamsite, State Line mine, Penn.	greenish-white, massive, translucent	massive			1.559	1.564	.005	2V(−)
36	Williamsite, Texas, Pennsylvania	dark green, massive, opaque	massive			1.563	1.568	.005	2V(−) small

* Refers to collection number.

Table IV. (*Continued*)

No.*	Specimen and Locality	Description	Nature of fragment	Extinction of fragment	Elongation of fragment	α	γ	$\gamma-\alpha$	Optic sign
37	Antigorite, Trafoss, Styria	leek green, massive, platy	massive, platy			$\beta=$ 1.575			2V(−) small
42	Marmolite, New Zealand	dark green, semi-platy	splintery	parallel	positive	1.566	1.572	.006	2V(−) small
57	Baltimorite, Bare Hills, Md.	grayish-green, brittle fiber	splintery	parallel	positive	1.559	1.565	.006	2V(−)
101	Bowenite, Lincoln, R.I. U.S.N.M. C-3772	grayish-white, massive, opaque	massive			1.557	1.562	.005	2V(−)
8	"Serpentine," Texas. Antigorite	green, brittle fiber to platy	splintery	parallel	positive	1.561	1.566	.005	2V(−)
52	"Serpentine," Chester Co., Penn. Antigorite	dark green, semi-platy	massive, platy			1.564	1.569	.005	2V(−) small
63	Picrosmine, Toblitz, Saxony	medium green, brittle fiber to columnar	splintery	parallel	positive	1.558	1.565	.007	2V(−) small
69	"Serpentine," Staten Island, N.Y. Antigorite	dark green, brittle fiber to platy	splintery		positive	1.558	1.565	.007	2V(−) small
78	"Serpentine," altered pyroxene, Md. Antigorite	green, massive to splintery	splintery	parallel	positive	1.563	1.568	.005	2V(−)
100	Porcellophite, Staten Island, N.Y.	grayish-green, massive, opaque	massive			1.558	1.563	.005	2V(−)

* Refers to collection number.

TABLE V. DEWEYLITE

No.*	Specimen and Locality	Description	Nature of fragment	Extinction of fragment	Elongation of fragment	α	γ	$\gamma-\alpha$	Optic sign
31	Deweylite, Texas, Pennsylvania. U.S.N.M. 9757	amber, incoherent masses	massive			near 1.500	near 1.509	.009	2V(+) small
34	Deweylite, Delaware, Pennsylvania	white, granular, with quartz	massive			1.487 var.	1.510 var.	low	
35	Deweylite, New Rochelle, N.Y.	white, massive, opaque	massive						
51	"Serpentine," after pectolite. Deweylite. Jersey City, N.J.	gray, massive, radiating	massive elongate	parallel	positive	1.538	1.546	.008	
104	Deweylite, Lancaster County, Pennsylvania	light tan, gum-like masses	massive			$n=$ 1.500			2V(+)

* Refers to collection number.

splintery nature in thin section. Their optically positive character can possibly be explained on the basis of a closer optical relationship to chrysotile than to massive serpentine. It would have been of interest to find a serpentine with massive fragments and positive optical character.

The birefringence of chrysotile apparently has a much broader range than that of massive serpentine or antigorite. This is also true of some members of the brittle, splintery serpentine in Table III.

The optical properties of deweylite have been included in this study because of its close relationship to serpentine. These are listed in Table V. In general it appears that the indices of refraction of deweylite vary over a wide range. The material from Pennsylvania has $n=1.500$ as an average. The grains are composed of aggregates and concentric structures of radiating fibers similar in appearance to chalcedony. The extreme limits of the indices are those shown in #34. The actual birefringence is much lower than the indices indicate. It is probably in the neighborhood of .009 as is shown in #31. The indices listed here are those in which the index of refraction of the maximum number of grains appeared to equal that of the liquids.

No explanation could be found for the higher indices of No. 51. Duplicate x-ray patterns show that it is deweylite. Optically it approaches serpentine.

The indices of the manganiferous serpentine from Franklin Furnace have been determined by Larsen[22] to be as follows: $\alpha=1.561$, $\gamma=1.568$, $\gamma-\alpha=0.007$. The mineral is biaxial negative. The indices fall close to those of bowlingite and antigorite in Larsen's Tables.

Thin Section Study

Various specimens from each group were selected for thin section study. Their selection was based on the results obtained from the x-ray and fragment studies. Minor amounts of impurities, chiefly carbonate or metallics, are present in some of the sections. Usually these are not found in sufficient quantities to give lines on the x-ray patterns. In several of the patterns of serpentine three extra lines appear which are attributed to some impurity. A chlorite like mineral is present in two of the thin sections made from specimens showing the extra lines in the x-ray patterns. In the pearly marmolite from Hoboken (#6) the impurity occurs in such a fine scaly form that it gives the whole thin section an iridescent appearance. The serpentine is seen by itself only on the edges of the thin section. This chlorite-like mineral is biaxial negative. The indices are similar to those of serpentine. Its birefringence is low. The lamellar structure of the serpentine is probably due to this mineral and not to an inherent characteristic.

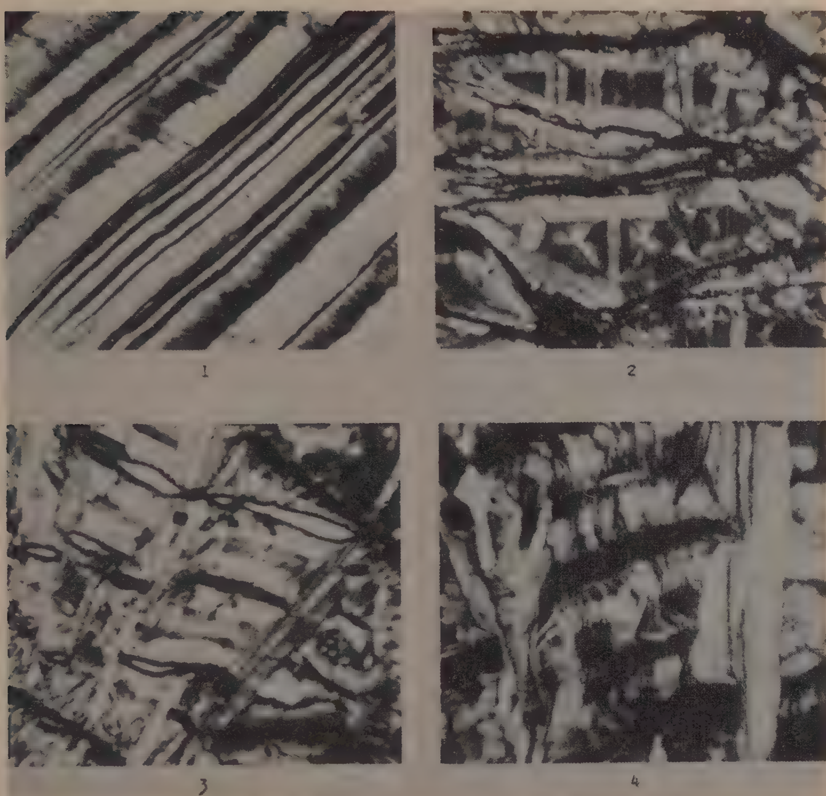


PLATE II

FIG. 1. Serpentine (#1) from Turkey Mountain, N.J., showing fibers and bands. ×56

FIG. 2. Hour glass structure as developed in bastite from Baste, in Harz, Germany. ×56

FIG. 3. Serpentine (#20) from Somerville, N.J., showing mesh structure. ×30

FIG. 4. The same field as is shown in Fig. 3. ×56

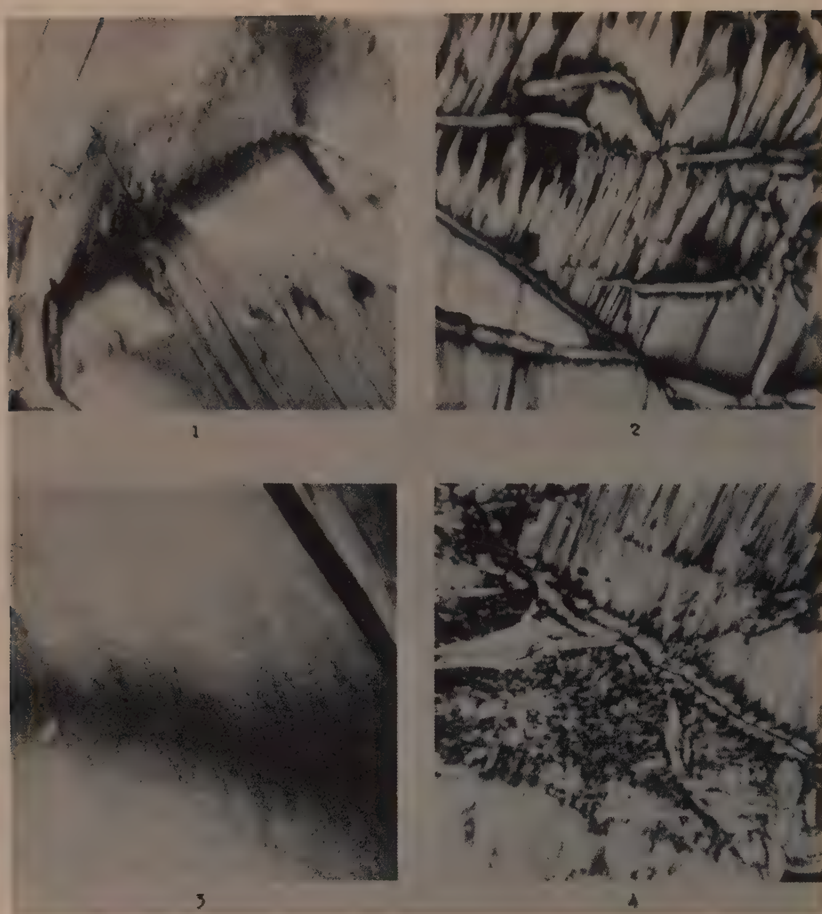


PLATE III

FIG. 1. Retinalite (#66) from Montville, N.J., showing pseudo-lamellae and severed fibers. ×56

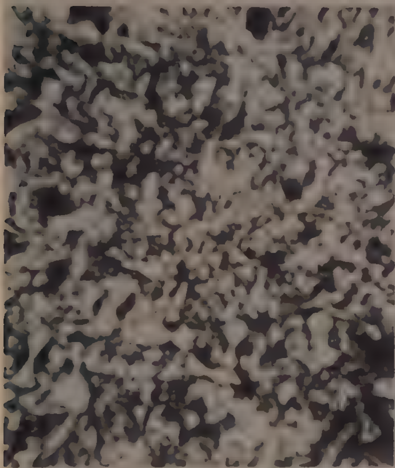
FIG. 2. Serrated structures in retinalite (#66) from Montville, N.J. ×23

FIG. 3. Sweeping extinction in schweizerite (#38) from Zermatt, Tyrol. ×15

FIG. 4. Williamsite (#5) from the State Line mine, Pennsylvania. ×56

1

2



3

4

PLATE IV

FIG. 1. Vein-like mass of fibers in antigorite (#2) from Antigorio valley, Piedmont, Italy. ×56

FIG. 2. Showing the vein-like mass of Fig. 1 on slight rotation of the stage. ×56

FIG. 3. Bowenite (#27) from Smithfield, Rhode Island. ×56

FIG. 4. Mottled extinction in picrosmine (#63) from Toblitz, Saxony. ×56

The study of the thin sections of both groups shows that the fundamental structure of each can be considered as fibrous. This property is much more evident when strong artificial light is used. Very little detail can be seen in the sections in plain light because of their low relief and lack of color. They appear as flat, structureless surfaces with the iris diaphragm contracted. The slides of antigorite, Nos. 2 and 37, are the only ones showing a faint tinge of color. Pleochroism is not observable in any of the sections. The fibers form larger structural units of varying aspect depending on their orientation and size. A question might arise concerning the boundary between elongated cleavage units and fibers. When viewed under higher magnifications, needle-like to lath-like units are resolved into still finer units of clearly fibrous appearance. Some of the larger structural units have duplicates in both of the groups. In some cases it is difficult to distinguish optically the group to which a specimen belongs because of the similarity of these features. Aggregates, anhedral units, structureless fields, veins, mesh structures, hour glass structures, etc., occur both individually and in combinations of two or more. The typical mesh structure found in the alteration of olivine to serpentine is the only one limited to serpentine. It appears from the study of the thin sections of the two groups that both are composed of warped planes of fibers, which are bent and twisted. In antigorite these possibly form coarser, coherent units to give it the described cleavage which is so little evident in thin section. The description of various thin sections of serpentine and antigorite will present the difficulties that can be encountered when one attempts to draw a sharp line, optically, between the two groups.

Descriptions of Serpentine.

Specimen #17, labelled gymnite, is really serpentine as shown by the x-ray pattern, and not a variety of deweylite, although it has an appearance, in hand specimen, similar to that of deweylite #35. In thin section it is composed of short, lath-like units which form elliptical to polygonal boundaries around carbonate, and weakly anisotropic to isotropic centers of serpentine. These units appear to have followed the crystal boundaries of the carbonate. They are distinctly fibrous, possess positive elongation and show wavy, approximately parallel extinction. Cleavage is not observable. These brighter anisotropic units compose so much of the material that they would definitely show in the x-ray pattern if they were antigorite. These units are similar in appearance to some in the sections of bowenite and "serpentine" #23 in the antigorite group.

The fibrous nature of the amber serpentine (#1), from Turkey Moun-

tain New Jersey, is distinctly shown in Fig. 1, Plate II. The fibers occur, roughly oriented, in tabular to anhedral units of varying sizes. A possible parting can be seen along the severed ends of a few units. All of the fibers possess negative elongation. They are, therefore, optically similar to the alpha serpentine described by Tertsch. The extinction is distinctly wavy, indicating that the fibers are not oriented in a strictly parallel sense, but that they are interlaced with their fiber axes roughly oriented in one direction. Marked inclined extinction is not uncommon. Some of the units exhibit mottled extinction similar to that shown in Fig. 4, Plate IV, while others exhibit fine grained aggregate extinction.

The bands in the figure are not due to polysynthetic twinning as some of the finer ones appear to be under low magnification. They are tabular layers of fibers that have been cut diagonally. The layers vary in width and usually narrow down and pinch out on the ends as the three narrow bands do in the lower left hand corner of the photograph. This indicates warping of the fibrous planes in more than one direction. The bands usually occur in distinctly fibrous fields similar to those shown in Fig. 1, Plate III. This banding may become so fine that it appears as if the fibers run at right angles to their true fiber direction. (See Fig. 3). This effect gives one an erroneous elongation. The banding is explained as due to microfolding of the fibers in an anhedral unit. The section is cut roughly parallel to the direction of the fibers. Each time there is a slight bending the fibers are cut off as shown in Fig. 4. The shorter the distance between the crests of the folds, the closer the bands lie together. This same banded effect is also produced by sharply folded, unsevered fibers that have been moved sidewise in the plane of the section. A serpentine (#3) from Staten Island shows this type of folding accompanied by microfaulting.

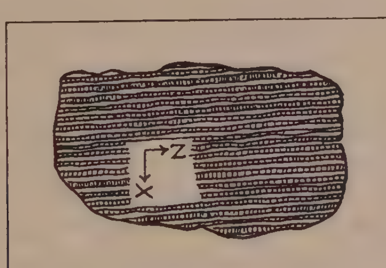


FIG. 3. A fibrous unit showing the optical orientation of the fibers in the false fiber effect produced by microscopic banding.

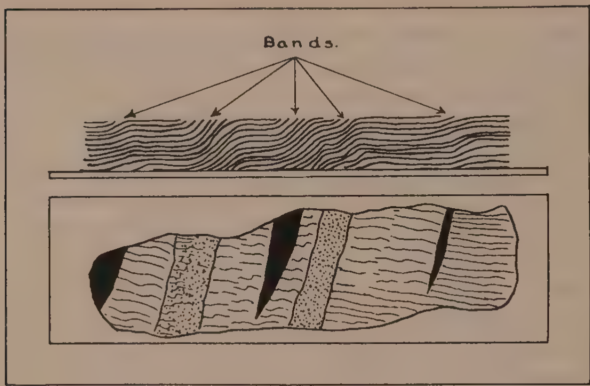


FIG. 4. A plan and section of a fibrous unit showing banding.

Fig. 1, Plate III, representing a section of retinalite (#66) from Montville, New Jersey, shows the pseudo-lamellar units that can be produced when a section is cut parallel to the direction of the fibers. The fibrous nature of the unit can be seen in the dark border and the area just above it. The units show wavy to mottled extinction, thereby indicating that the fibers are not perfectly parallel. The fibers have dominant negative elongation and variable angles of extinction. The dark lines, which are distinctly anisotropic, are not due to cleavage but to planes of differently oriented fibers. Under the microscope incipient serrated structures, similar to those shown in Fig. 2, Plate III, can be seen along the dark border. The borders produced by cutting off the fibers transversely or on the bias can be traced until they narrow down and disappear in a homogeneous, fibrous field. Several small cone-like bulges can be seen near the lower right hand corner of Fig. 1, Plate III. They owe their presence to a slight upwarp of the fibers in the unit. The bulges may become changed sufficiently in orientation to produce the borders or the serrated forms of Fig. 2, Plate III.

A fine structureless aggregate occurs where the anhedral units have been cut off at right angles to the length of the fibers. The thin sections consist of mixed areas of pseudo-lamellar fields, serrated fields and structureless aggregates due to the diversity of orientation and size of the fibrous, anhedral units composing the specimen.

Fig. 2, Plate III, is a photograph taken of the same thin section as Fig. 1, Plate III. Two tabular units, showing the severed ends of the fibers, join to form a V. Above these, the serrated figures are developed to a high degree. These serrated figures are formed in an adjoining unit which is differently oriented from the units composing the two surfaces

of the V. This serrated field can be traced upward with the number of peaks diminishing and finally ending in a fibrous, pseudo-lamellar field with undulous extinction and bordered with the ends of clipped fibers. Incipient serrated structures can be seen along the edges of the V. These are more clearly defined with a slight rotation of the stage. The serrated structures possess negative elongation when they have a small angle of extinction and closely parallel the fiber direction of the pseudo-lamellar unit.

Probably the most diagnostic structure of serpentine is the mesh structure which is formed in the alteration of olivine to serpentine. Excellent examples of this structure are found in serpentine (#20) from Somerville, New Jersey. (See Fig. 3, Plate II.) Rows of meshes are usually bounded by two veins of some length with short, transverse veins between them. The centers of the veins may be isotropic, weakly anisotropic or strongly anisotropic between crossed nicols. Sometimes they consist of a string of metallics. When the center of the vein is anisotropic, as distinctly shown in Fig. 3, Plate II, it is always found to have the axis of least ease of vibration normal to its length. (See Fig. 5). An undulous extinction indicates that it is probably fibrous. It is usually impossible to determine in what direction the fibers are oriented. However, a few of the centers show that the fibers are oriented normal to the length of the vein. This type of fiber is comparable to chrysotile and the gamma serpentine of Tertsch.[16] The brighter birefringent centers may form lenses. At times these lenses pinch out until they are nothing more than a single line. This narrow line can be detected in many of the weakly anisotropic to isotropic centers. It always shows that the axis of least ease of vibration lies normal to its length.

The edges of the veins are composed of twisted fibers that appear interlaced under higher magnification. These form the borders of the meshes. They possess negative elongation and are, therefore, alpha serpentine. The centers of the fields, which are usually weakly anisotropic, sometimes react as if the fibers composing them had their axis of least ease of vibration parallel to their length. With closer study and higher magnification it is clearly seen, in all cases, that the centers of the fields are composed of the fibers bordering the edges of the mesh. The lower birefringence of the center of the mesh is probably due to the compensating effect of the matted fibers. This also explains the weakly anisotropic to isotropic fringes that separate the edges of the veins from the brightly anisotropic center.

In tracing the centers of the veins they are found to vary from the

[16] *Op. cit.*

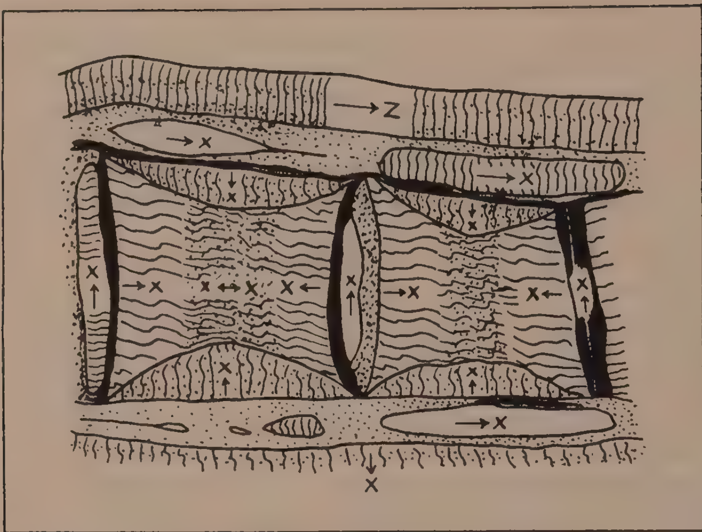


FIG. 5. A diagrammatic sketch showing the optical orientation of the fibers in mesh structure serpentine from Somerville, New Jersey.

distinctly anisotropic material through weakly anisotropic to isotropic material. At the same time the width of the centers narrows until it pinches out or continues only as a fine line with the result that the fibers bordering the vein meet in the center without a line of demarcation. This suggests that the material with positive elongation (gamma serpentine) possibly exists as lenses in a field of fibers with negative elongation (alpha serpentine).

A few scattered areas composed of brightly birefringent fibers with negative elongation are noted. They are bordered by weakly anisotropic material. This same type of fiber is sometimes noted to terminate the fibrous edges of veins that do not form mesh structures. They are usually coarser and lie more nearly parallel than the fibers that terminate in the centers of the meshes. Their birefringence is probably due to the fact that compensation, caused by matting of the fibers, is absent.

Some meshes possess higher birefringent fibers in their centers than on their borders, the reverse of what is shown in Fig. 3, Plate II. In all of the slides, the fibers immediately bordering the centers of vein-like structures possess negative elongation and, therefore, are alpha serpentine. No structures are to be seen comparable to the window structure described by Tertsch.

Fig. 2, Plate II, shows hour-glass structure as developed in bastite

(#105) from Baste, in Harz, Germany. The dark centers of the veins are usually composed of strings of metallics. Rarely a structureless, weakly anisotropic band is present instead of the metallics. The axis of least ease of vibration of this band, if present, is normal to its length. The bordering transverse fibers, which usually occur sufficiently coarse to be distinctly visible, possess negative elongation. The fibers of the fields forming the hour-glass structure vary from distinctly visible, twisted units down to such a size that their presence is only surmised by the wavy extinction produced by rotation of the stage. Their fiber direction is optically negative. The sectors of the fields in which it is impossible to determine the direction of the fibers show the axis of least ease of vibration normal to the length of the veins. Fundamentally this structure is comparable to the mesh structure described above.

The centers of the fields are usually weakly anisotropic to isotropic. The lines that mark the sectors are sometimes chiefly due to the effects of extinction rather than a visible demarcation between fibers of different orientation. The material as a whole is so finely fibrous that it is only with difficulty that the fibers bordering the centers of the veins can be traced into the centers of the fields as they were, with greater ease, in the mesh structure previously described.

A peculiar lense-like structure composed of hour-glass units is formed when two strings of metallics and their accompanying bands join to form one string. This is partially shown on the left hand side of the bottom row of hour glass structures in Fig. 2, Plate II.

Here, as in the mesh structure described above, the widths of the center of the veins are variable, whether they are composed of metallics or serpentine. They narrow down at times until there is no center left. The fibers then pass from one line of hour glass structures to another without interruption. Their fiber direction remains optically negative.

The bastite which has been described in this study is associated with a pyroxene which possesses a metalloidal luster in hand specimen. In thin section the veins of serpentine can be traced into the pyroxene. This type of bastite probably agrees more closely with the fibrous bastite described by Lewis[23] and referred to by Angel[18] as "bastitfaser" than to the descriptions of platy varieties by Winchell,[6] Du Rietz[24] and others.

A homogeneous field, composed of twisted, interlaced fibers, of schweizerite (#38) from Zermatt, Tyrol, is shown in Fig. 3, Plate III. The extinction sweeps across the field after a fashion which is similar to an isogyre of an optic figure. A coarser structure, which is barely evident

[18] *Op. cit.*

[6] *Op. cit.*, p. 377.

in the thin section, parallels the crack and the vertical cross hair. The section as a unit has positive elongation as was also noted in the fragment study.

The specimens described in the above thin sections are serpentine. These vary from material composed wholly of fibers with negative elongation, through material of mixed fibers of both positive and negative elongation, to fibrous material wholly composed of fibers with positive elongation. The fragments of the first four are massive while those of the last are splintery.

Descriptions of Antigorite.

Fig, 1, Plate IV, of antigorite (#2) from Antigorio valley, Piedmont, shows a distinctly fibrous vein-like mass running across a mottled field. Slight rotation of the stage causes it to blend into the surrounding matted field (Fig. 2, Plate IV). This vein-like mass has been formed by the severing of upturned fibers. Sometimes the fibrous masses are cut off in step-like forms showing positive elongation parallel to the length of the fiber and negative elongation along the direction in which the fiber has been cut. There is not the least indication of a lamellar structure as shown by the micas, chlorites, etc., even in specially cut oriented sections. There are a few higher birefringent, relatively long, wavy streaks that show the material has a fibrous or cleavable orientation. This is only observed where the material has been slightly pulled apart in making the thin section. Fine hair-like fibers usually join the separated units.

The material is somewhat impure as indicated by its cloudy appearance in thin section. The impurity is probably associated with it in fine, dispersed particles. In the original description by Schweizer the mineral was described as non-crystalline and thinly foliated. No mention was made of an existing cleavage. The term slaty would probably describe the hand specimen better than lamellar.

Fig. 4, Plate III, of williamsite (#5) from the State Line mine, Pennsylvania, shows the radial, interwoven, leaf-like forms with wavy extinction and positive elongation that appear somewhat similar to the serrated structures of serpentine (#66) shown in Fig. 2, Plate III. One difference noted is that the leaves appear as individuals rather than forming a unit as they do in specimen #66. The darker area is composed of the severed ends of the units. In some of the areas, where the units are finer grained, and come to points, they are identical to parts of specimen #66. Only a little parting or cleavage can be noted on small individual fragments that run transverse to the leaf structures. These usually occur on top of the clipped units. They possess positive elongation and parallel extinction, although the extinction usually appears wavy. Under higher

magnification the ends of the units have a ragged appearance and assume a brittle fiber aspect. The long diagonal veinlet traversing the center of the picture is due to the material being bent over in making the section. It has a typical fiber structure. The dark line down the center is due to a crack in the material. This specimen, which is grouped with antigorite, is probably the coarsest developed member of the group. It does not show either lamellar structure or pseudo-lamellar units. None of the individuals give a distinct total extinction. Regardless of size or orientation the extinction is always wavy.

Fig. 3, Plate IV, of bowenite (#27) from Smithfield, Rhode Island, shows a fine aggregate chiefly composed of structureless units possessing positive elongation. The extinction of all the aggregate is distinctly wavy or radial. In the center of the picture are two cross-like units composed of radiating members. When one observes the ragged ends of each small unit under high magnification, they appear to be definitely fibrous rather than lamellar. The extinction is undulatory even in the smallest unit. Cleavage does not appear in the aggregate. It is probable that Angel described material similar to this as being composed of interlaced antigorite twins. In contrast to this Niggli[25] states, "the nephrite-like, apple green to greenish-white bowenite is only recognizable as a fibrous aggregate under the microscope."

Fig. 4, Plate IV, of picrosmine (#63) from Toblitz, shows the mottled extinction produced under crossed nicols by a distinctly fibrous variety of antigorite. The sides and ends of the section are distinctly fibrous although there is not the least indication of a cleavage in the body of the section. The fibers are interlaced and differently oriented. With rotation of the stage neither a relatively light or dark field is obtained.

The fibrous nature of antigorite is further exemplified by baltimorite (#57). The material is associated with carbonate in the hand specimen. The mineral consists of brittle, columnar units of some length. These units can be divided into easily separable, fine, brittle fibers. In thin section the mineral forms a solid homogeneous field without cleavage indications. It possesses mass extinction. The true nature of the mineral is only seen on the ends of the slide and where it has been torn in making the thin section. Here the fine fibers are readily seen. Long lath-like units are formed where the material has been parted mechanically. They possess parallel extinction and positive elongation. Material such as this could be considered lamellar if occurring in a massive rock and surrounded by grains on all sides which would hold it together sufficiently to keep the fibers from being separated. Occasional parting parallel to the direction of the fibers could be considered as indications of cleavage.

Descriptions of Deweylite

The slide of deweylite (#104) shows the typical concentric forms attributed to the mineral. These are composed of a rim of radiating fibers enclosing an aggregate center. The structure developed by the fibers is similar to that of chalcedony. The fibers possess positive elongation and wavy, approximately parallel extinction. Their relief is definitely negative.

A thin section of deweylite (#51), pseudomorphous after pectolite, shows that the mineral was broken into numerous lath-like units in making the section. They parallel the length of the relict, radiating structure of the pectolite. The units possess positive elongation and parallel extinction. Concentric structures are not noted.

Discussion and Conclusions Based on Optical Studies

The slides that have been described above are illustrative of the structural features observed. These slides were selected as examples and are considered typical. Many other slides have been studied which duplicate the features illustrated. Sometimes the entire slide serves as an illustration; at other times combinations of two or more of the described features may occur. The optical studies did not show that any of the specimens could be combinations of the two minerals, serpentine and antigorite. This is confirmed by the x-ray patterns.

Two platy varieties have been identified as the mineral serpentine. These are marmolite from Hoboken and thermophyllite from Finland. The marmolite was originally described as a thin foliated, brittle, lamellar mineral with a pearly luster. Although it was recognized from the chemical analysis that the mineral could be considered a serpentine, it was given a new name because of its crystalline character. Later Vanuxem[25] reanalyzed the mineral and concluded that marmolite corresponded with serpentine in all of its important physical and chemical characters with the exception of its chrystalline structure and the luster. The study of the thin sections shows that a foreign mineral occurs in such fine laminated form that it gives an iridescence. It is due to the presence of this mineral impurity that marmolite owes its false foliation and luster. The optical properties of marmolite indicate that it is the mineral serpentine. This is confirmed by the x-ray pattern.

In thin section thermophyllite shows abundant mica distributed through the serpentine. Here, as in the marmolite, the foliated structure is due to the impurity and not to the serpentine. Thus it appears that foliation is not an inherent characteristic of the mineral serpentine. Serpentine can then be described as occurring in hand specimen either in massive or brittle, splintery forms. Microscopically all of the specimens

are composed of fibers which form structureless aggregates or anhedral units of varying aspect. These fibers are of two classes: those that show negative elongation (alpha serpentine) and those that show positive elongation (gamma serpentine). The latter are comparable to chrysotile fibers. The optic sign may be either positive or negative with the negative sign predominating. When the fibers become of sufficient size and coarseness to be recognized in the hand specimen the mineral may be called chrysotile to denote its asbestos-like properties. The usage agrees with the original definition.

In the antigorite group doubt exists whether antigorite from Antigorio is truly lamellar as the micas, chlorites, etc., are considered, or whether the structure is a stress feature. This material breaks in large sheets with a slaty parting. In thin section it is distinctly fibrous. A certain twisting of the fibers is evident throughout the section. The fibers rarely appear to form thin, warped planes that are comparable to the units produced by the slaty parting. There is nothing in the sections that would indicate a lamellar mineral.

Breithaupt originally described picrosmine with a prismatic cleavage. Later Frenzel[27] described a picrosmine, with columnar structure, which was easily cleavable into parallel columns. Under the microscope this showed a finely fibrous structure. This is also true of the picrosmine (#63) described above. Such observations suggest that either fundamentally antigorite is composed of cleavage units so fine that the mineral has the appearance of being fibrous, or cleavage does not exist. Optically it would probably be difficult indeed to distinguish between the brittle, splintery type of serpentine and the corresponding type of antigorite. This is partially shown in Dana's System where metaxite, a serpentine mineral, is classed as a variety of picrolite, an antigorite mineral.

An interesting observation was noted in the thin section study. No veins of the type that form the mesh structures in serpentine were noted in any of the thin sections of antigorite. Further it was observed, both in thin section and in hand specimen, that chrysotile did not accompany any of the antigorite specimens of the study. Specimens Nos. 1, 12, 21, 44, 45, 46, 47, 66, 67, 68, 77 and 110 are associated with veins of chrysotile. These specimens are grouped in the serpentine tables. They represent material from Montville, N.J.; Globe, Arizona; Thetford, Quebec; the Ural mountains; Southern Rhodesia; and Morristown, Vermont. This suggests that the matrix of chrysotile is serpentine and not the mineral antigorite, as is thought by some authors. This appears more plausible when the interplanar spacings are considered. The transformation of serpentine to chrysotile would only require a recrystallization with probably negligible change in the interplanar distances. For chryso-

tile to originate in antigorite would not only require recrystallization but an appreciable change in the interplanar distances to account for the differences between the patterns of serpentine and antigorite. A detailed study of the matrix of chrysotile from many more localities will be needed to prove or disprove this suggestion, but it is significant, at least, that such a group of samples as listed above is in agreement.

The Chemistry of the Serpentine Group and Deweylite

Serpentine and antigorite are considered dimorphous forms of the same compound, $H_4Mg_3Si_2O_9$. Tables VII and VIII list analyses compiled from the literature. Some are the original analyses given with the description of the specimen while others are re-analyses of purer material. None are recent and, therefore, all are only relatively dependable.* They were selected, partly, to represent the type mineral species described and, partly, because the description of the analyzed specimens tallied closely with that of some of the studied specimens.

Table VII. Serpentine

No.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	H_2O	Na_2O	NiO	MnO	Total
1	43.50	0.40		2.08	40.00		13.80				98.78
2	41.58	0.42		1.69	42.61		13.70				100.00
3	42.42	0.63	0.62		41.01	tr	15.64		0.23		100.55
4	40.23	2.18	4.02		39.46		14.24				100.13
5	42.38	0.07	0.97	0.17	42.14		14.12				99.85
6	42.72	0.20	0.68		43.38	0.38	13.40				100.76
7	42.05		0.30	0.10	42.57	0.05	14.66				99.73
8	41.47	1.73		0.09	41.70		15.06				100.05
9	41.59		2.43		42.32		13.55				99.89
10	41.87	2.30			42.43		13.40				100.00
11	42.00	0.26		0.90	41.00		15.00				99.16
12	42.73			2.79	40.37	0.40	12.17	1.52			99.98
13	41.48	5.49		1.59	37.42		10.88	2.84			99.70
14	43.66	0.64		1.96	41.12		13.57				100.95
15	43.12	4.91		1.99	34.87		13.13	1.33			99.36
16	41.21			1.72	39.24		16.16			0.30	98.63

1. Chrysotile, Reichenstein. Kobell.[28]
2. Chrysotile, Goujot. Delesse.[29]
3. Chrysotile, Montville. Clarke and Schneider.[30]
4. Serpentine (green), Montville. Merrill.[31]
5. Serpentine (yellow), Montville. Merrill.[31]

* Mr. J. J. Fahey has kindly supplied more recent analyses which largely confirm the selection included in this paper. A few may be modified slightly on re-analysis. Mr. Fahey will cover this subject in a later paper. In the present discussion the chemical nature of the serpentine minerals is considered only in general terms.

6. Serpentine, Montville. Hillebrand.[32]
7. Serpentine (dull green), Montville. Clarke and Schneider.[30]
8. Serpentine (dark green), Newburyport. Clarke and Schneider.[30]
9. Serpentine, Snarum. Fogy.[33]
10. Serpentine (pseudo-cubic), Tilly Foster. Allen.[34]
11. Marmolite, Hoboken. Kobell.[35]
12. Metaxite, Reichenstein. Bauer.[36]
13. Thermophyllite, Finland. Northcote.[37]
14. Schweizerite, Zermatt. Schweizer.[38]
15. Thermophyllite, Finland. Hermann.[39]
16. Vorhauserite, Monzoni. Kenngott.[40]

TABLE VIII. ANTIGORITE

No.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	H_2O	NiO	Total
1	41.58	2.60		7.22	36.80		12.67		100.87
2	41.14	3.82	3.01		39.16	0.40	11.85		99.38
3	42.94		3.33	1.88	36.53		13.21	1.61	100.22
4	43.79			2.05	41.03		12.47		99.34
5	41.13	1.23		1.49	43.65	0.17	12.46		100.13
6	42.20	tr		1.56	42.50	tr	13.28		99.54
7	42.50	tr		0.95	43.15	tr	12.84		99.50
8	42.60			1.62	41.90		12.70	0.40	99.22
9	44.50	0.75		1.39	39.70		12.75	0.90	99.99
10	40.95	1.50		10.05	34.70		12.60		99.80
11	44.08	0.30		1.17	40.87		13.70		100.49

1. Antigorite, Antigorio, Brush.[41]
2. Antigorite, Sprechenstein. Hussak.[42]
3. Picrolite, Buck Creek, Clay County, N.C. Clarke and Schneider.[30]
4. Picrolite, Texas, Pennsylvania. Rammelsberg.[43]
5. Bowenite, Shigar, Kashmir. McMahon.[44]
6. Bowenite, Smithfield, R.I. Smith and Brush.[45]
7. Bowenite, Smithfield, R.I. Smith and Brush.[45]
8. Williamsite, Texas, Pennsylvania. Smith and Brush.[45]
9. Williamsite, Texas, Pennsylvania. Herman.[46]
10. Baltimorite, Bare Hills, Md. Thompson.[47]
11. Porcellophite. Dana's System.[48]

DEWEYLITE

No.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	H_2O	Total
1	43.15	tr			35.95		20.25	99.35
2	40.16	tr	1.16		36.00	0.80	21.60	99.72

1. Deweylite, Texas, Pennsylvania. Brush.[48]
2. Deweylite, Bare Hills, Md. Thompson.[47]

A review of the analyses of serpentine in Table VII shows that all agree reasonably well. The same is true of the analyses of antigorite in Table VIII. In comparing the average analyses of serpentine and antigorite a few minor differences can be noted. The magnesia and water content are slightly lower in antigorite than in serpentine. The difference in the water content is more marked than the difference in the magnesia content. This decrease in water in antigorite appears to accompany the slight increase in the average indices of antigorite over those of serpentine.

The analyses of deweylite are included because of the close structural and chemical relationship between deweylite and serpentine. The formula of deweylite is considered to be 4 $MgO.3\ SiO_2.6\ H_2O$. The formula of serpentine, given in the same way, is 3 $MgO.2\ SiO_2.2\ H_2O$. The close structural and chemical relationship between the two minerals, along with published analyses of varying water content, suggests that there may be a series of isomorphous minerals between the two groups. This could only be verified by a combination of detailed optical, chemical and x-ray investigation of the hydrous magnesium silicates that are listed close to deweylite and serpentine. The low indices of deweylite from Pennsylvania are accompanied by a marked increase in the water content of the mineral.

The deweylite pattern of specimen #51, which displayed optical characters similar to those near the low index end of serpentine, indicates the need for further study of the relationship between deweylite and serpentine. Likewise the low indices of refraction of serpentine #95 are difficult to explain in view of the data at hand.

Conclusions Based on Combined X-ray and Optical Studies and Chemical Discussion

The x-ray and optical studies show that the varieties listed under serpentine are similar in interplanar spacing and closely related optically. The chemical composition does not vary sufficiently to divide the group into different minerals. Although the varieties have a distinctive structural appearance in thin section, this should not be considered a sufficient basis for a separate name. The structures are not characteristic of the mineral serpentine, but are relict structures superimposed on the mineral by an environmental condition. It appears, therefore, that the names schweizerite, metaxite, pyroidesine, marmolite, retinalite, thermophyllite, bastite and vorhauserite should be dropped as distinct species names in the favor of the one term, serpentine.

For the same reasons given in the case of the mineral serpentine, it is

proposed in the case of the mineral antigorite to drop the names picrolite, williamsite, bowenite, porcellophite and baltimorite.

The mineral names serpentine and antigorite have been used in this study in a definite sense. Chrysotile is the flexible fiber form of serpentine. The mineral serpentine continues to designate the type of mineral to which the name was originally applied. The usage proposed in this paper continues the name antigorite, now in common use (although picrolite has priority) as a distinct mineral of the serpentine group. Antigorite and serpentine may not be dimorphous, although chemical analyses do not agree well enough to definitely prove or disprove this relationship.

The term serpentinite is suggested for rocks composed either of serpentine or antigorite, or both together. This rock term would lend itself more easily to the field or laboratory description until the mineral composition is correctly determined. Confusion would thus be avoided in designating the two minerals and the rock.

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SEPARATION PLANES IN MAGNETITE

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During the course of an investigation of the equilibrium relationships of Fe_3O_4, Fe_2O_3, and oxygen we had occasion to use some of the very pure magnetite from the Lovers' Pit at Mineville, N.Y. This material occurs as granular magnetite and faceted crystals. It is remarkable for the size of the masses with uniform orientation, and for the perfection of a system of intersecting planes parallel to the octahedral directions of the magnetite, along which it separates when broken. The faces of the crystals are marked by striae where these separation planes outcrop. A close inspection shows that there are other separation planes and striae in addition to the octahedral ones.

Following Cathrein[1] and Mügge[2] such separations, parallel to the octahedron, in magnetite, are usually attributed to polysynthetic spinel twinning, the planes along which the separation takes place being then composition planes or planes common to two individuals, and therefore parting planes. However, Kemp[3] in describing magnetite crystals from this locality expressed a doubt that the separation planes in them were due to polysynthetic twinning. He said: "The beds that contain them have been subjected to great dynamic movements and these partings are very probably due to pressure—which has developed the fine pseudo-cleavage planes in the massive mineral. If it were allowable to conceive of a chief parting[4] along 0, and a rarer one along ∞0, occasioned by such pressure, without any accompanying twinning, I should think it more likely to be the true cause of the phenomena." Professor Kemp's drawing of one of these crystals showing the striae on its faces gives an excellent idea of their appearance. This drawing will be familiar to most readers for it has been reproduced in Dana's System and in the Textbook to illustrate notes on polysynthetic twinning.

A preliminary examination of our Mineville material disclosed no sign of twinning so we obtained some other specimens together with a number of magnetites from other localities and studied them[5] (see Table 1). These specimens included a number of good crystals showing striations on their faces, and a number of pieces showing well developed planes, often with striations on them.

[1] Cathrein, A., *Zeit. f. Kryst.*, vol. **12**, pp. 47–49, 1886.

[2] Mügge, O., *Neues Jahrbuch f. Min.*, vol. **1**, pp. 244–246, 1889.

[3] Kemp, J. F., *Am. Jour. Sci.*, vol. **40**, pp. 63–64, 1890.

[4] The term "parting" is evidently not used here in the same sense in which it is used in the first sentence of this paragraph.

[5] We are indebted to Drs. William F. Foshag and E. P. Henderson for their kindness in supplying these specimens from the collections of the U. S. National Museum.

TABLE 1. LIST OF MAGNETITES EXAMINED

The numbers are the U. S. National Museum numbers of the specimens. All were examined in polished section after partial oxidation, (g) indicates that an examination was made with the goniometer. The form symbols indicate separation planes in the cases in which they were found. Transparent filling was found in some of the separation planes in each specimen that showed these planes.

Mineville, N.Y. Crystals and fragments. Several samples including 47725 and 47830. (g), (111), (110), (831).

Pt. Henry, N.Y. 79343. Fragments. (g), (111), (110), (100).

Nigger Hill Mine, Warren Co., N.Y. 11603. Fragments. (g), (111), (110), (100).

Nordst jernegrafvan Westaufors, Sweden. 48972. Fragments. (g), (111), (100).

Texas, Lancaster Co., Pa. 83432. Octahedra in schist. (111) not very common.

Cedar City, Utah. 99484. Lodestone. Rather earthy looking on fractured surface. No sign of separation planes. Partial oxidation shows that it is made up of small differently oriented units.

Magnet Cove, Ark. 83701. No sign of separation planes. Partial oxidation results in extremely minute hematite lamellae distributed through the material.

Brewster, N.Y. R 1972. Dodecahedra. No indication of separation planes.

Tilley Foster Mine, N.Y. R 1974. Dodecahedra. No indication of separation planes.

French Creek, Chester Co., Pa. 48534. Crystal faces stepped, resulting in curved appearance. No indication of separation planes. Only a very slight tendency for the hematite formed by partial oxidation to form lamellae parallel to the (111) planes of the magnetite.

Several of these crystals and a number of fragments were examined on the goniometer. No signals from faces in the twinned position were obtainable from any of the striations on crystal faces. The fragments likewise, with one exception, gave no indication of twinning. In the single exception, the planes giving signals belonged to two individuals with the angular relationship of spinel twins.

An examination of each of these magnetites was also made by partially oxidizing the material, then examining polished sections under the microscope. The hematite that is formed when the magnetite is heated in air at an appropriate temperature is usually[6] arranged in thin lamellae lying parallel to the octahedral planes of the magnetite. The sizes of the lamellae vary greatly from one specimen to another. From the angles between the outcrops of the lamellae on the polished surface it is a simple matter to determine the orientation of the magnetite[7] (see Figs. 1, 2, and 3). Since, in most cases, when small pieces of magnetite are partially oxidized in this way, the hematite lamellae are not confined to a narrow

[6] Magnetite from French Creek, Chester Co., Pa., U. S. Nat. Museum No. 48534 is exceptional. The hematite formed when the material is heated in air at 1000° shows scarcely any tendency to the usual arrangement.

[7] *Am. Jour. Sci.*, vol. **30**, p. 311, 1935.

zone surrounding the specimen, but also appear scattered throughout the interior, partial oxidization usually provides us with a means of determining the orientation of the magnetite in any desired part of the polished surface.

FIG. 1. Polished section of a fragment of magnetite from Pt. Henry, N.Y., U. S. Nat. Museum No. 79343. ×375. Partially oxidized by being heated in air at 950°–1000°. The bright portions are hematite, the ground is magnetite. The parallel continuous lines of hematite running NE–SW mark separation planes parallel to one octahedral plane. The surface of the fragment that was exposed to the air during oxidation is shown on both sides in the upper part of the photograph. Note that the short lamellae of hematite are distributed throughout, as is also the case in the other two figures.

In contrast to these short, widely distributed lamellae the separation planes in the partially oxidized magnetites are represented by fairly continuous sheets of hematite (see Figs. 1, 2, and 3). A thin sheet of hematite usually develops along these planes before much appears in the main body of the magnetite, and from it short lamellae extend into the magnetite on each side, and thus show its orientation. In no case did we

FIG. 2. Polished section of magnetite from the Nigger Hill Mine, U. S. Nat. Museum No. 11603, partially oxidized in air at 950°–1000°. ×740. The bright portions are hematite, the ground is magnetite. The continuous narrow line of hematite running NE–SW marks an octahedral separation plane. The two parallel zones of more numerous short hematite lamellae, crossing the middle of the photograph nearly horizontally, mark the outcrops of two separation planes or potential separation planes parallel to the dodecahedron.

find any change in the orientation of the magnetite along one of these planes. There is always, of course, a layer converted to hematite, whose orientation cannot be found, but by controlling the oxidation this layer may usually be kept very thin. In the more favorable cases it was quite evident that if there had been any layer of magnetite, with an orientation different from that of the main body, the width of its outcrop must have been less than 0.001 mm. Yet in this work, as in the goniometric work, no evidence of polysynthetic twinning was found.

It was stated above that one example of individuals with the angular relationship of spinel twins was found with the goniometer. The piece showing it was partially oxidized, sectioned, and examined with the microscope. The polished surface showed two good-sized areas of uni-

FIG. 3. Another polished surface of a partially oxidized fragment from the Nigger Hill Mine. ×740. One octahedral separation plane crosses the photograph running NE–SW. Above it a curved fracture shows. In this as in the other photographs it can be seen that the short lamellae of hematite produced by the oxidation provide a key to the orientation of the magnetite, and permit one to place an upper limit to the width of the outcrop of any possible twin lamella lying along a separation plane.

form orientation, and the angles of the outcrops of the hematite lamellae on this surface showed again that the two individuals were related to each other according to the spinel law. But, although each individual showed also a number of separation planes, there was no indication of polysynthetic twinning, and, since the surface separating the two individuals was not a plane, it was evident that this relationship was not secondary.

Besides the octahedral separation planes, which in some specimens are so closely spaced and brilliant as to appear like a perfect cleavage, several other much poorer separation planes have been observed in these magnetites. Kemp noted that planes parallel to the dodecahedron occurred in the Mineville material, and we found that pieces from several

localities when mounted on the goniometer showed dodecahedral or cubic separation planes or both.

In the case of some very good octahedra from Mineville there are striae that can be traced half-way around the crystals. The planes, of which these are the outcrops, represent the form (831). This is rather surprising for this form is not mentioned in Dana or in the Winkeltabellen as having been observed on magnetite.

Thus we find no evidence of polysynthetic twinning as a cause of the octahedral separation planes in these magnetites. Moreover we find separation planes with an orientation—(831)—that is extremely improbable as a composition plane, and still others with orientations—(110) and (100)—that preclude twinning as the cause.

As a rule these other planes are much less conspicuous on the polished surface of the partially oxidized magnetite than are the octahedral separation planes. In some cases they are indicated by a somewhat discontinuous line of small, irregularly shaped areas of hematite. In other cases they appear as zones of more or less closely spaced small hematite lamellae lying parallel to the octahedral planes (see Fig. 2).

Openings along many of these planes have been filled with silicates. This transparent material is sometimes visible under the Greenough binocular as an iridescent film on exposed surfaces. In some cases it shows up when a polished section is examined under the microscope, and it is probable that it is also present in many cases when it is too thin to be seen in this way.

It is evident that the separation planes are the result of some special conditions to which these magnetites were subjected while still in the earth.[8] Their development is considered to be analogous to the develop-

[8] We have made some observations that suggest that the development of small lamellae of hematite throughout the interior of a grain of magnetite while it is being heated in air is, like the development of the separation planes, a consequence of the forces to which it was subjected while in the earth. Among the magnetites that we examined there were some from three different sources in which the oxidation—while resulting in the typical lamellae lying parallel to the octahedral planes of the magnetite—was confined pretty well to the outer layer, or to zones along irregular fractures, and only slowly advanced into the interior. None of these showed any development of the separation planes. They are: synthetic magnetite, crystals from Brewster, N.Y., U.S. Nat. Museum No. R 1972, crystals from the Tilley Foster mine, U. S. Nat. Museum No. R 1974. All the magnetites that showed a good development of separation planes showed also a good development of small hematite lamellae in the interior, but so did several that did not show separation planes. Usually the hematite lamellae are distributed more or less uniformly between all four octahedral planes. However, the partial oxidation of some magnetite from Port Henry resulted in a striking exception. There was a pronouncedly preferential development of the lamellae parallel to one octahedral plane. This difference in directions, that in a normal isometric crystal are equivalent, must be the result of outside forces.

ment of jointing in rocks, but with the crystal structure of the magnetite as well as the differential pressure exercising control. This conclusion is obviously in harmony with Kemp's idea quoted above. It does not, of course, deny the occurrence of polysynthetic twinning as a cause of parting in some magnetites.

Magnetite is described as a mineral without a distinct cleavage, and our observations are in agreement with this description. We have examined a great number of polished surfaces of synthetic magnetite. Although the material spalls readily and the polished surface pits on standing we saw no indication of cleavage. When the magnetites described above, that show such a pronounced development of separation planes, are crushed, much of the breaking is along these planes at first, but, as crushing is continued, more and more conchoidal fractures develop, as if the plane surfaces were formed only where pre-arranged or pre-existing. With other magnetites all surfaces formed by crushing appear conchoidal or at most to have only steplike modifications of the conchoidal surface.

Summary

A number of magnetites showing separation planes were examined to see whether or not they offered any support for the customary explanation of this pseudo-cleavage, i.e., that it is parting along the composition planes between twins. No evidence of this could be found. Although the octahedral separation planes are much the most common and best developed, separation planes were also found parallel to some faces of three other forms, (831), (110), and (100). The orientation of the first of these makes twinning extremely improbable and the orientations of the other two make it impossible as a cause of the separation planes. Silicate has been deposited in openings along many of these planes. It is believed that the separation planes in these magnetites were developed without twinning by differential pressure, much as joints are produced in rocks, but with the crystal structure as well as the differential pressure exercising control.

HYDROTHERMAL ALTERATION OF MONTMORILLONITE TO FELDSPAR AT TEMPERATURES FROM 245°C. TO 300°C.

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INTRODUCTION

Feldspar has been made synthetically at temperatures as low as 300°C.[2] In these experiments one common procedure was to mix dialyzed SiO_2 and Al_2O_3 in an aqueous alkaline solution and heat the mixture in a steel bomb for a long period of time.

The writer made a number of experiments based on somewhat different reasoning. The mineral montmorillonite has a layer structure[3] whose theoretical formula is $(OH)_2\ Al_2Si_4O_{10} \cdot mH_2O$. It resembles muscovite closely except for the absence of K and a larger ratio of Si to Al. In place of K ions the mineral seems to have H_2O molecules between the well known $(OH)_4\ Al_4Si_8O_{20}$ layers, common to both minerals. Montmorillonite is so finely divided that its *x*-ray diffraction lines are broad and diffused. It should, therefore, react chemically much more easily than substances of a coarser grain, especially since the above mentioned layers can be forced apart to a certain extent by an excess of H_2O in the system.[4] It should be possible to replace the water by other molecules or ions, or to cause a complete and easy rearrangement of the structure.

EXPERIMENTS AND X-RAY DATA

A montmorillonite (bentonite) from an unknown locality was used. It is a dense pinkish white material and gives the typical *x*-ray powder diagram of montmorillonite. The diagram of this material was published by the writer in this journal.[5] Half a gram of the sample was put in a gold lined bomb of 50 cc. capacity. Ten cc. of a solution of 1 gm. of $KHCO_3$ in 10 cc. of distilled water were added. The distilled water was boiled just before use. The air above the solution was displaced by CO_2, and the bomb sealed with a sheet of gold. It was placed in a furnace whose temperature was controlled by a Leeds and Northrup potentiometer recorder to ± 3°C. Since the bombs were thick walled and heavy the tem-

[1] This study was aided by liberal grants from the Graduate School of the University of Minnesota.

[2] For a detailed description with numerous references see: *Doelter's Handbuch der Mineralchemie*, vol. **2**, pp. 556–567, 1917.

[3] Hofmann, Endell and Wilm, Kristallstruktur und Quellung von Montmorillonite: *Zeit. Krist.*, vol **86**, pp. 340–348, 1933.

[4] Hofmann, Endell and Wilm, *Op. cit.*, p. 345.

[5] Gruner, J. W., The structural relationship of nontronite and montmorillonite: *Am. Mineral.*, vol. **20**, p. 478, 1935.

peratures inside were probably closer to the mean furnace temperature than the extremes recorded by the potentiometer. After completion of an experiment the gold sheet was welded to the gold lining of the bomb, due to the great pressure. The bomb was opened by cutting a circular hole through the sheet. In most experiments in which $KHCO_3$ solution was used, a pressure of CO_2 was noticed when the bomb was opened. The solid material was rinsed into a beaker and then washed thoroughly by repeated decantations, after which it was air-dried for *x*-ray analysis. A microscopic investigation showed the material was so fine grained that only rough values for refractive indices could be obtained. These are within the range of orthoclase.

The lengths of time for the experiments with $KHCO_3$ varied. Seven days was sufficient at 300°C. to produce an orthoclase which yielded a relatively good *x*-ray pattern (see Table 1). Ten days at 272°C. produced practically the same result though the lines in the film are not quite as clear and more diffused. Two weeks at 245°C. yielded material whose lines were broad but approximately in the positions of orthoclase. Due to the diffuse character this pattern cannot be definitely correlated with orthoclase. Six weeks at 245°C. gave a diagram of orthoclase but not so good as the one recorded in Table 1, which is the result of three months heating at 245°C.

Six weeks at 200°C. did not produce any marked change in the montmorillonite pattern. If orthoclase forms at all at this temperature it probably requires time measured in years.

Table 1 contains the interplanar distances *d* and intensities *I* of adularia and three of the alteration products. The distances are uncorrected for eccentricity of the camera. The powders were mounted on silk thread and were about 0.8 mm. thick. Fe radiation was used to obtain maximum resolution of lines. The lines of the alteration products, especially those of 272°C. and 245°C., are relatively broad and in some cases overlapping, as compared with adularia. This is as would be expected in such extremely fine-grained material. Many of the small discrepancies in *d* values are due to the difficulty of finding the exact outer edges of diffuse lines. Line No. 1*a* occurs only in the last two alteration products. It does not belong to orthoclase. It may be due possibly to remaining montmorillonite which has one of its strongest reflections in this region. Other lines of montmorillonite coincide or overlap with orthoclase lines and therefore would be obscured. It is possible, then, that remnants of the original mineral structure still exist. The periodic spacing of the layers must have been, however, badly disturbed or destroyed for the most characteristic and intense basal reflection (001) at *d* 15Å has disappeared.

TABLE 1. COMPARISON OF X-RAY POWDER PHOTOGRAPHS OF ADULARIA WITH ALTERATION PRODUCTS OF MONTMORILLONITE. Fe RADIATION. RADIUS OF CAMERA 57.3 MM.

Line No.	Adularia Pfitsch Tyrol		7 days at 300°		10 days at 272°		3 months at 245°	
	d	*I*	*d*	*I*	*d*	*I*	*d*	*I*
1	4.68	1*b*						
1*a*					4.53	2	4.52	2
2	4.21	3	4.18	2	4.21	1	4.20	2
3	3.94	0.5			3.91	1	3.91	1
4	3.77	2	3.77	2	3.75	1	3.78	2
5	3.61	1			3.59	0.5	3.61	0.5
6	3.480	1	3.43	1	3.43	0.5	3.44	0.5
7	3.313	5	3.313	4	3.292	3	3.290	4
8	3.227	4	3.204	3	3.195	2	3.192	3
9	2.995	2	2.980	1	2.975	2	2.980	3
10	2.901	1	2.880	1	2.880	2	2.892	2
11	2.763	1	2.743	0.5	2.739	0.5	2.752	0.5
12	2.560	3	2.567	3*b*	2.573	3*b*	2.577	3*b*
13	2.378	1	2.383	1	2.394	1	2.394	1
14	2.319	0.5						
15	2.263	0.5			2.269	0.5	2.260	0.5
16	2.165	2	2.161	2	2.164	1	2.164	2
17	2.119	1	2.116	1	2.116	0.5	2.112	1
18	2.050	0.5	2.053	0.5			2.058	0.5
19	1.999	1	2.002	0.5	2.007	0.5	2.004	1
20	1.968	1	1.964	1	1.967	1	1.965	1
21	1.915	1	1.926	1	1.922	0.5	1.919	1
22	1.881	0.5						
23	1.848	1	1.840	0.5	1.840	1	1.837	0.5
24	1.792	4	1.786	3	1.782	2	1.785	2
25	1.768	1						
26	1.740	0.5						
27	1.718	0.5			1.716	0.5		
28	1.690	0.5						
29	1.671	0.5	1.666	0.5	1.675	0.5	1.670	0.5
30	1.643	0.5	1.645	0.5	1.648	0.5		
31	1.622	1	1.620	0.5	1.616	0.5		
32	1.589	0.5	1.583	0.5				
33	1.565	1	1.555	0.5	1.563	1	1.560	0.5
34	1.528	1						
35	1.510	1	1.511	1*d*	1.516	2*d*	1.518	3*d*
36	1.490	3	1.493	2	1.496	2	1.493	2
37	1.474	0.5	1.471	0.5	1.475	0.5		
38	1.447	1	1.452	0.5	1.449	0.5		
39	1.435	1	1.427	0.5	1.431	1	1.429	1
40	1.422	0.5						
41	1.402	1	1.401	0.5	1.404	0.5	1.402	1

TABLE 1. (*Continued*)

Line No.	Adularia Pfitsch Tyrol		7 days at 300°		10 days at 272°		3 months at 245°	
	d	*I*	*d*	*I*	*d*	*I*	*d*	*I*
42	1.381	1	1.378	0.5	1.377	0.5	1.375	0.5
43	1.345	0.5						
44	1.334	1			1.335	0.5		
45	1.312	0.5					1.310	0.5
46	1.294	0.5	1.303	1*d*	1.304	1*d*	1.294	0.5
47	1.284	1	1.285	1	1.283	0.5		
48	1.273	1	1.270	0.5	1.272	0.5	1.278	1
49	1.264	1					1.260	0.5
50	1.253	1	1.248	0.5	1.247	0.5		

b = broad line
d = double line

The reaction occurring in the bomb may be expressed by the following equation:

$$3[(OH)_2Al_2Si_4O_{10}\cdot 2H_2O]+4KHCO_3\rightarrow$$
$$4KAlSi_3O_8+2Al(OH)_3+8H_2O+4CO_2$$

It will be noticed that aluminum hydroxide is one of the products. This might have remained in the colloidal state in which case it would have been decanted with the wash water. The first water from the beaker had a somewhat milky appearance. At any rate, *x*-rays did not reveal the presence of a crystallized hydroxide.

One may wonder why K_2CO_3 solutions were not used in any of the experiments. This reagent dissolves completely large quantities of the mineral, unless it is added in just the proper combining proportion which obviously is not feasible in the case of montmorillonite. Otherwise, it may have the same effect as $KHCO_3$.

The following equation

$$3[(OH)_2Al_2Si_4O_{10}\cdot 2H_2O]+2KHCO_3\rightarrow$$
$$2[K(OH)_2Al_2(Si_3Al)O_{10}]+6SiO_2+2CO_2+8H_2O$$

expresses a reaction producing muscovite from montmorillonite. This reaction on the basis of simple structural considerations should be expected to occur more easily than the one yielding orthoclase. No explanation for its absence can be advanced by the writer at present.

In one experiment a ten per cent solution of KCl was tried at 300°C. After 19 days no change was noticeable in the *x*-ray pattern of the montmorillonite.

Conclusions

Montmorillonite was heated in aqueous solutions of $KHCO_3$ in gold-lined pressure bombs. Seven days at 300°C. produced good orthoclase. The *x*-ray powder photograph is easily identified as that of adularia. At 272°C. the feldspar pattern became distinct after 10 days. At 245°C. six weeks to three months were necessary to produce the orthoclase structure. Six weeks at 200°C., on the other hand, had no apparent effect on montmorillonite. Potassium chloride solution (10%) does not seem to attack montmorillonite at 300°C. in 19 days. Muscovite, which by reason of its structural similarity could have been expected to form from montmorillonite, failed to appear in any of the experiments. The probable reaction in the bombs is as follows:

$$3[(OH)_2Al_2Si_4O_{10}\cdot 2H_2O]+4KHCO_3\rightarrow$$
$$4KAlSi_3O_8+2Al(OH)_3+8H_2O+4CO_2$$

While it is highly probable that orthoclase may form at temperatures below 245°C. it is impossible to make an estimate as to the lowest temperature of formation. The finding of authigenic feldspars in sedimentary rocks seems to indicate temperatures at least as low as 100°C.

DEVITRIFIED FELSITE DIKES FROM ASCUTNEY MOUNTAIN, VERMONT

Robert Balk, *Mount Holyoke College*, and Philip Krieger, *Columbia University*.

Introduction

The stock of gabbro and nordmarkite penetrating the ancient gneisses and phyllites of Ascutney mountain, Vermont, is associated with various dike rocks. Among the leucocratic types, and probably connected with the nordmarkite, Daly[1] describes paisanitic dikes which strikingly resemble fine-grained phases of the main stock. During a brief visit to the region in 1933, a few glass-bearing dikes were observed that contain spherulites. They have not been previously mentioned, and appear to have some bearing on the depth at which the stock consolidated. The field relations were studied by Balk and the petrographic examination made by Krieger.

Field Relations

Fine grained, aphanitic dikes, cutting the gneiss as well as the gabbro and nordmarkite porphyry, were found at four localities. (1) Near the top of hill 980 feet, one mile northeast of Ascutney Notch, (Claremont quadrangle, Vermont-New Hampshire), the hornblende gneiss is traversed by a group of splintery, grayish-white, aphanitic dikes striking north-south and dipping in various directions. The dikes vary in thickness from three to 27 feet and can be followed along their strike for approximately 600 feet. At this locality they do not appear to reach the intrusive stock. (2) At the crest of Little Ascutney mountain (Ludlow quadrangle, Vermont) the nordmarkite porphyry is cut by another dike. The contact of the dike and nordmarkite at this locality is well defined. This dike strikes northwest-southeast and dips 75 degrees northeast. Where best exposed, the dike is one foot thick but attains somewhat greater thickness at other places along the strike. Loose blocks of the dike were also found in the paisanite area as mapped by Daly.[2] (3) About 15 dikes outcrop in the hornblende gneiss of hill 1040 feet, one and one-half miles northwest of Pierson Peak (five millimeters south of letter "o" of "Robins*o*n Hill," Ludlow quadrangle). Some of these dikes are perfectly straight whereas others curve with the strike of the gneiss, which here forms a northward pitching syncline. All of these dikes are short and rarely traceable for more than 30 feet, although some resemble rows of lenses which appear to be connected below the surface. Although rudely parallel to the foliation of the gneiss, the

[1] Daly, R. A., The geology of Ascutney mountain, Vermont: *U. S. Geol. Survey, Bull.* **209**, 1903.

[2] *Op. cit.*

contact planes, nevertheless, cut the folia at acute angles. These dikes vary in thickness from one-half inch to five feet or more. A few additional dikes outcrop some 1200 feet southeast of this locality along the southwest slope of hill 1060 feet. (4) The largest dike was observed along a brook just south of the private road one-half mile west of Pierson Peak (Ludlow quadrangle). This dike strikes east-west and attains a thickness of over 100 feet. The brook follows the strike of the dike for approximately 600 feet and exposures along it are continuous and fresh. Both the gneiss and the gabbro are cut by the dike.

A laminated structure due to the alignment of flow layers is present in all of the dikes and is especially intense in the thinner ones. The flow layers follow the contacts and abut sharply against the foliation of the gneiss and also of the gabbro when the latter rock is foliated. At locality (1) flow layers of the largest dike display well developed isoclinal folds, the limbs of which join the contacts (Fig. 1).

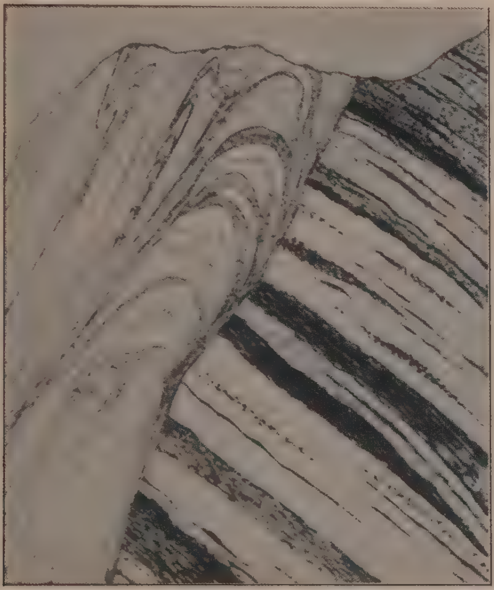


Fig. 1. Field sketch of devitrified felsite dike, cutting foliation of hornblende gneiss, near top of hill 980′, 1 mile NE of Ascutney Notch, Claremont quadr., Vt.,-N.H. Area 9 by 7 feet. Looking north. Note isoclinal folds of spherulite-bearing layers (dark stippled). The dike dips west at an angle of 70°.

Most of the dikes are aphanitic in texture, although the interior of the thick dike at locality (4) is slightly porphyritic and shows small phenocrysts of feldspar and an occasional grain of biotite or hornblende. In addition, porphyritic facies appear locally in the form of irregular,

bale-shaped masses, ranging in width from a fraction of an inch to about four inches, with aphanitic facies filling spaces between these areas. At locality (1) the rock exhibits fine linear streaks on the flow layers which share trend and pitch with the axes of the folds in the dikes. The streaks appear to be composed of rows of minute sericite flakes.

The most noteworthy feature of the dikes is the occurrence of small spherulitic nodules which are aligned in directions parallel to the flow layers and participate in their contortions and bends (Fig. 1). A petrographic examination of several spherulitic specimens was made.

The geologic relations suggest that the dikes are related to the paisanitic dikes described by Daly. They resemble these rocks in the field and analysis of the interior portion of the thick dike at locality (4) shows an alkali content not greatly different from those of Daly's[3] analyses of the paisanitic rocks (Table 2). The aphanitic dikes, however, show a distinct prevalence of potash over soda (Table 1), and it would seem as if the last residues differed somewhat from a true nordmarkitic magma. The spherulitic nodules, with their devitrified shells, suggest that the stock of Mt. Ascutney had arrived at a fairly shallow level in the crust when the last dikes consolidated.

TABLE 1. CHEMICAL ANALYSIS OF DEVITRIFIED FELSITE DIKE, NEAR TOP OF HILL 980 FEET, 1 MILE NE OF ASCUTNEY NOTCH, CLAREMONT QUADRANGLE, VT.,-N.H.
R. B. ELLESTAD, *analyst.*

	SiO_2	67.61
	Al_2O_3	16.78
	Fe_2O_3	0.42
	FeO	1.52
	MgO	0.75
	CaO	0.85
	Na_2O	0.96
	K_2O	9.36
	H_2O+	0.72
	H_2O-	0.08
	CO_2	0.44
	TiO_2	0.11
Spec. gravity	2.644	99.60

TABLE 2. ANALYSIS OF ALKALIES IN CENTRAL PORTION OF THICK FELSITE DIKE, BROOK ONE HALF MILE WEST OF PIERSON PEAK (LUDLOW QUADR., VT.).
E. H. EMENDORFER, *analyst.*

CaO	0.46
Na_2O	4.84
K_2O	3.93
	9.23

[3] *Op. cit.*, p. 75.

Petrography

Megascopic Characteristics. A hand specimen of the felsite is light gray to brown in color, uniformly fine grained or felsitic in texture, with moderately well developed flow structure and a fine incipient jointing. The latter feature is best seen on a polished slab of the rock. Minerals that can be identified megascopically consist of small feldspar phenocrysts up to two or three millimeters in diameter, and a few scattered grains of pyrite. Inspection with a hand lens shows numerous small spherulites, which rarely exceed more than one half millimeter in diameter. The rock weathers to a rusty brown color that is readily distinguishable from the light gray color of the gneiss in which it occurs.

Along the contact of the felsite and the gneiss a narrow band, or selvage, of dark colored ferro-magnesian minerals is usually present. The width of this band is from 10 to 20 millimeters and the color, on a polished slab of the rock, contrasts strongly with the felsite and the gneiss.

Microscopic Features. The microscope reveals a highly devitrified, glassy groundmass enclosing numerous spherulites of feldspathic material. Phenocrysts of feldspar are also fairly abundant in most of the specimens. Some of these show good polysynthetic twinning and have optical properties which would place them in the oligoclase-albite range. Others show good carlsbad twinning with optical properties corre-

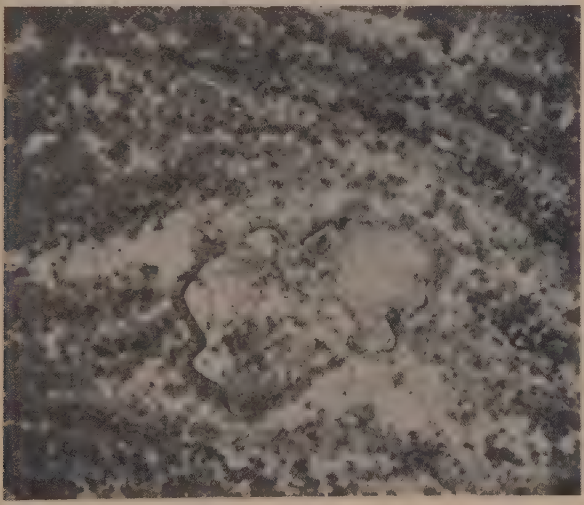


Fig. 2. Photomicrograph of the felsite dike rock showing a cluster of feldspar phenocrysts and spherulites, the latter aligned along the flow layers of the rock. ×22.

sponding to those of orthoclase. Flow structure is well developed in all of the specimens examined.

Feldspar phenocrysts occur as individual crystals and as aggregate groups of crystals distributed throughout the glassy and spherulitic groundmass. Almost invariably they contain numerous liquid or gaseous inclusions which, in most cases, appear to be concentrated in the central portion of the phenocryst. That the magma was still highly fluid after these crystals had formed is evidenced by the well-defined flow structure passing around individual crystals or crystal aggregates (Fig. 2). Some of the feldspar phenocrysts show alteration to flaky sericite. This may have been brought about by the still fluid portion of the magma or by the introduction of deuteric quartz with which the rock appears to have been swamped during the latter stages of its consolidation (Fig. 3).

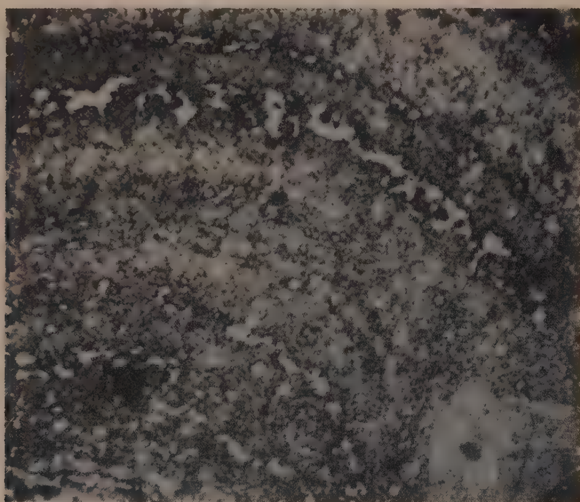


FIG. 3. Photomicrograph showing flow structure of the felsite and the manner in which quartz (clear white areas) occurs along the flow layers. A portion of an altered feldspar phenocryst is also shown. ×22.

Spherulitic growths are abundant in most of the specimens examined. They are usually closely grouped and often coalesce to form numerous clusters which are arranged roughly parallel to the flow structure of the rock. The spherulites consist of numerous small microlites that originally appear to have crystallized in the radiate manner characteristic of such growths. Intense devitrification of the glassy groundmass, however, and the introduction of additional quartz, has modified them to such an extent that good radial extinction is but occasionally observed. The general

form of the spherulites, however, is usually well preserved. What the original composition of the spherulites may have been could not be definitely determined. As they frequently show alteration to fine, flaky sericitic material, however, it is judged that they were largely felspathic in composition.

The original glassy groundmass of the rocks has been highly devitrified and, where not affected by other processes, now consists of finely crystalline areas made up of minute interlocking grains which show good polarization effects. Although the individual grains are too small to permit determination of optical properties, it is judged that they consist of quartz and an acid feldspar, the latter showing alteration to sericitic material.

In addition to the devitrified groundmass, the rocks also contain many irregular, blotchy areas consisting of larger interlocking quartz grains (Fig. 4). Individual grains in these areas seem to be too large to

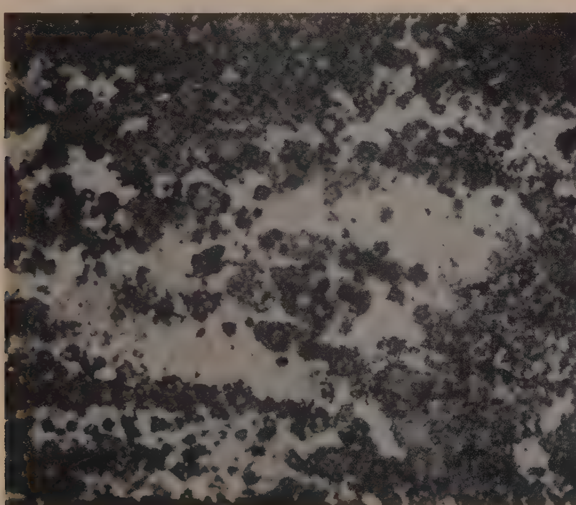


Fig. 4. Photomicrograph showing spherulites and the occurrence of quartz (white areas) which has replaced some of the glassy groundmass. The blotchy habit is typical of the late stage quartz in these rocks. $\times 22$.

have been the result of simple devitrification. The blotchy appearance of these areas, and the manner in which they occur, suggest that they are not the result of devitrification. This material occupies interstitial areas between spherulites and appears to have replaced the groundmass in preference to the spherulitic nodules. Many of these areas extend along flow layers, participating in their contortions and bends. This quartz

does not occur in veinlets, but simply as irregular, blotchy areas, nor is there any evidence in the rock to indicate areas of weakness or fracturing along which material may have been introduced. For these reasons it is believed that this material was not introduced from an outside source after complete consolidation of the rock, but that it represents deuteric quartz with which the dike rock was swamped either while still in a slightly viscous state or immediately after being chilled.

An interesting feature of some of the dike rocks is the occurrence of numerous nodules which are made up of exceedingly minute, interlocking grains showing but faint polarization effects. This material occurs as individual nodules, and also as rims surrounding feldspar phenocrysts, in a groundmass of highly devitrified and altered glassy material (Fig. 5). When surrounding phenocrysts of orthoclase, the index of refraction of this material is nearly identical to that of the feldspar, but

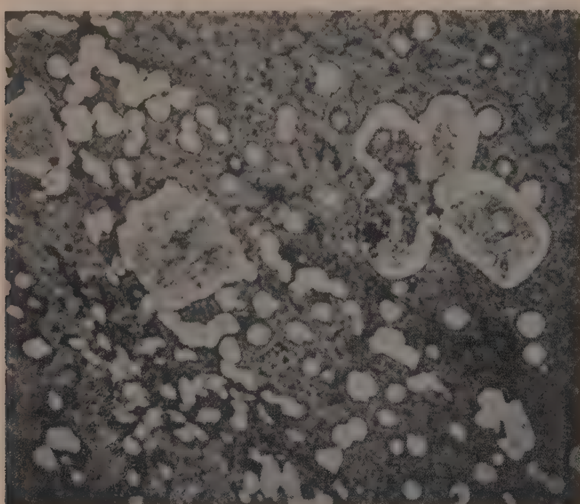


FIG. 5. Photomicrograph showing feldspar crystals and numerous nodules of nearly isotropic material in an altered and devitrified groundmass. The clear, white rim bordering the feldspar crystals is made up of the same material. ×22

it is so nearly isotropic that further optical determinations could not be made. The material making up such rims is later than the feldspar for occasionally it is seen to encroach and penetrate the feldspar in a manner suggesting replacement. These nodular forms do not resemble other spherulites in the rock, nor do they show the development of microlites, but are made up of finely devitrified glassy material.

THE DETERMINATION OF THE REFRACTIVE INDICES OF MINERALS BY THE IMMERSION METHOD

Chester B. Slawson and A. B. Peck,* *University of Michigan, Ann Arbor, Mich.*

The crystallographic-optical theory upon which the determination of the indices of refraction of a birefringent mineral by the immersion method is based, is very adequately treated in a number of texts, so it is not the purpose of this paper to approach the subject from that standpoint. But the application of this theory to the routine determination of minerals is an art which the student acquires chiefly by practice. The student finds himself confronted with the necessity of doing three things simultaneously, no one of which in itself would give him much difficulty, but taken together they contrive to delay his mastery of the petrographic microscope. The first essential, of course, is an understanding of the theory upon which the determinations of the indices of refraction are based; secondly, he must interpret his observations under the microscope in terms of this theory; and, thirdly, he must at the same time develop a manipulative technique or skill in the use of the microscope as a mechanical instrument. The present treatment is an attempt to bridge the gap between theory and practice.

In the great majority of cases the petrographic microscope is only a useful tool and the determination of the indices of refraction an important step in the identification of the mineral. Too often though, the emphasis is placed upon the refinement of procedure, and the main objective, the identification of the mineral, becomes subordinated to the method of attack. It is recognized that in certain types of research, accuracy in the determination of the optical constants becomes one of the main objectives of the problem. In general, however, the variations in the chemical composition within a single mineral species make extremely accurate determinations of little value, unless accompanied by a chemical analysis of the same material. It is hoped that nothing in this presentation will be interpreted as meaning that a thorough grounding in fundamental crystal optics is not desirable. The sole purpose is to present an exposition of a method that has been found satisfactory in the routine determination of the optical constants as a means of identifying minerals, in the hope that others may profit from it.

* Authors' Note—This is a presentation of some of the principles which have been used for a number of years in giving elementary instruction in the use of the petrographic microscope without a rigorous treatment of optical theory.

The use of the symbols o, e, $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{c}$, X, Y, and Z are not essential to the practical or to the theoretical study of crystal optics. Hence these terms are dropped and the vibration directions within a crystal are denoted by ω and ϵ for uniaxial crystals, and α, β, and γ for biaxial crystals. No confusion arises when these terms are used to denote not only the principal indices of refraction (scalar properties) but also the vibration directions within the crystal (vector properties) for the rays possessing those indices of refraction.

By the time the student is sufficiently advanced to begin using the petrographic microscope, his knowledge of the megascopic physical properties and the general appearance of the common minerals will often give a preliminary idea as to the identity of most specimens. In most cases the microscope will be used to check and confirm megascopic impressions, or to decide upon one of a number of possibilities. Consequently any routine method should not be so rigid as to require that an inordinate amount of time be devoted to prescribed preliminary preparations. In other words, the method should be flexible enough to allow it to be adapted to the problem at hand. As experience is acquired, crushed mineral fragments under the microscope take on definite characteristics which convey to the observer impressions as diagnostic as the visual impressions he associates with hand specimens. Because of these facts no definite procedure is recommended but each step is determined by the sum total of knowledge that has been acquired up to that point. With this in mind the choice of the first immersion liquid depends upon the specimen to be determined.

If the mineral is uniaxial every fragment will give ω in one of the extinction positions. If the variable index is greater than ω, the mineral is positive, and if less than ω, negative. It is not necessary to determine the sign from an interference figure but the uniaxial character should be observed from an interference figure whose optic axis emerges within the field to demonstrate that the mineral is not biaxial with a small optic angle. The exact value of ϵ may be determined only from those fragments in which the c-axis lies in the plane of the microscope stage. These fragments, which are analogous to those perpendicular to the optic normal, give in the extinction positions (when the brushes are crossed) centered interference figures like Fig. E. In both instances the movement of the brushes on rotating the stage is very rapid. Except for this more rapid movement of the brushes, the figures are also similar to those from sections perpendicular to the obtuse bisectrix (Fig. J). If the interference figure is not exactly centered, a value very closely approximating ϵ may be determined. In minerals with low or moderate double refraction the approximation is extremely close. Fragments from which ϵ may be de-

termined extinguish very rapidly and, if the material is of approximately uniform thickness, will show higher interference colors than the fragments in which the c-axis is not horizontal. Every doubly refractive fragment will give ω in one extinction position and ϵ, or a value intermediate between ω and ϵ, in the other extinction position.

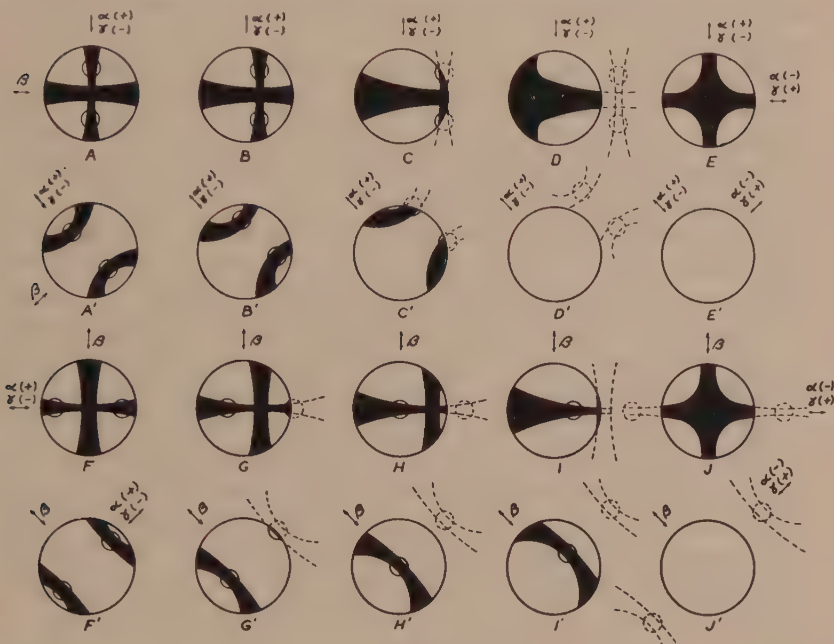


FIG. 1.

The value of ω can be easily determined with exactness and usually it is not necessary or advisable to determine ϵ with a corresponding accuracy in the routine determination of minerals. But whenever it is necessary to determine ϵ accurately, the orientation of the fragment should always be checked by observing an interference figure of the character described above.

In biaxial minerals α or γ may be determined from those fragments which are so oriented that *one* of the bisectrices lies in the plane of the microscope stage. Figures A–E show the types of interference figures given by fragments with the obtuse bisectrix lying in the plane of the microscope stage. In Fig. A, perpendicular to an acute bisectrix, the obtuse bisectrix is parallel to the plane of transmission of the polarizer. If we now think of the section as rotating to the right about the obtuse bisectrix as an axis of rotation we would obtain successively Figs. B, C, and D. Further rotation would bring the section perpendicular to the

optic normal as in Fig. E. Rotation to the left would have given similar figures but in reverse position. During the rotation the position of the obtuse bisectrix has remained fixed and the interference figure is always symmetrical to one direction of the field. Consequently any of these possible positions will permit α in a positive mineral and γ in a negative mineral to be compared with the liquid in which the fragment is immersed. Figures A′, B′, C′, D′, and E′ show the corresponding figures in the 45° position. Here the two brushes are still symmetrical to one direction in the field, when they fall within the field. When the interference figure is perpendicular to the optic normal (Fig. E), the acute bisectrix also lies in the plane of the microscope stage and therefore one extinction position will give α and the other γ.

The same argument may be developed for a similar series of interference figures starting with one cut perpendicular to the obtuse bisectrix in which case the acute bisectrix would lie in the plane of the microscope stage, and α would be determined from a negative mineral and γ from a positive mineral. In many cases when the optic angle approaches 90° it is impossible to distinguish the acute and obtuse bisectrices. This situation is covered by the following generalized conclusion. *If the observed bisectrix is positive* (as normally determined by the use of test plates) *α may be determined, and if negative γ may be determined.*[1]

In biaxial minerals, β may be determined from those fragments which are so oriented that the optic normal lies in the plane of the microscope stage. Figures F–J show the types of figures obtained from such fragments. In Fig. F, perpendicular to the acute bisectrix,[2] the optic normal is parallel to the plane of transmission of the polarizer. If we think of the fragment as rotating to the right about the optic normal as an axis of rotation we would obtain successively Figs. G, H, and I. Further rotation would bring the section perpendicular to the obtuse bisectrix as in Fig. J. Rotation to the left would give similar figures but in reverse position. During the rotation the position of the optic normal has remained fixed and consequently any of these possible positions will permit β to be compared with the liquid in which the fragment is immersed. When the interference figure is perpendicular to the obtuse bisectrix, Fig. J, the acute bisectrix also will lie in the plane of the microscope stage and on rotating the stage through 90° it will be parallel to the plane of transmission of the polarizer. Consequently, in that position, γ may be determined in positive minerals and α in negative minerals.

The student is apt to get the impression that only fragments showing interference figures perpendicular to either an optic axis, an acute or ob-

[1] This statement holds whether the mineral is positive or negative.

[2] Compare with Fig. A.

tuse bisectrix, or the optic normal are available for the determination of the principal indices of refraction. Actually, if any one of the three principal optical *sections* is vertical, one of the principal indices may be determined in the direction normal to that principal section by rotating the stage so that the normal to the principal section is parallel to the plane of transmission of the polarizer (the principal section being in the E–W position).

In accordance with the foregoing discussion the following general rules may be laid down:

From any fragment giving an interference figure possessing one plane of symmetry with reference to the field of vision,[3] *one of the principal indices may be determined (Figs. B, C, D, G, H, and I).* With the plane of symmetry lying in the E–W position, the index of refraction is determined in the N–S position.

From any fragment giving an interference figure possessing two planes of symmetry with respect to the field of vision,[4] *two of the principal indices may be determined (Figs. A, E, F, and J).* These correspond to the two extinction positions.

In practice it is generally true that the student does not crush his fragments fine enough. He also is very apt to use far too many fragments in a single immersion mount. He expects his interference figures to resemble those pictured in texts. As a rule the average interference figures will resemble those obtained from feldspars in rock sections of standard thickness, in respect to the width and sharpness of the "brushes" and lack of rings. If, because of a distinct cleavage, it is difficult to find properly oriented fragments, finely ground glass may be added to the crushed mineral.[5] Some of the pieces of glass will lie under the edges of the fragments and give to some fragments the desired orientation. Because of the isotropic character of the glass, this method should not cause confusion.

The index of the mineral and that of the immersion liquid can be best compared under high magnification, using an objective giving 45× magnification, for instance. Because of the difference in dispersion between the liquid and the mineral a spectrum is observed along the contact when the indices of the two are close. When the indices of the immersion liquids are standardized for definite wave lengths of light, semi-monochromatic determinations may be made in white light by observing

[3,4] Strictly speaking, this holds only for monochromatic light. The moderate dispersion observed in some monoclinic and triclinic minerals offers no serious difficulty to such a generalized statement.

[5] Larsen, Esper S., and Berman, Harry: *U. S. Geol. Survey, Bull.* **848**, p. 22.

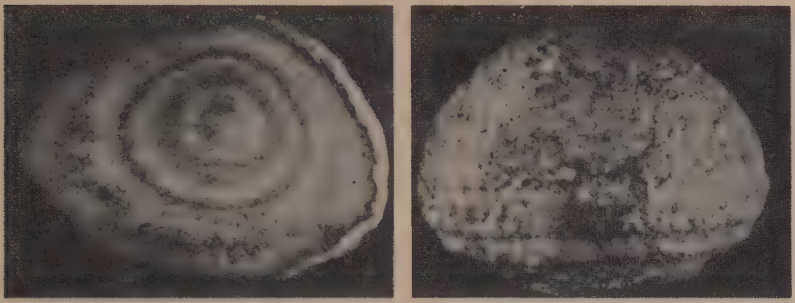
the movement of the colors of the spectrum along the contact between the mineral and the liquid.

In conclusion we wish to emphasize that there are in reality an infinite number of possible orientations available for the determination of each of the principal indices of refraction, that a routine procedure is not always desirable because experience points the way to "short-cuts," and that usually the errors involved in the method are smaller than the known variations of the indices within a mineral species. We also feel that methods based upon the use of fragments whose orientations have been observed are much to be preferred to statistical methods involving the determination of maximum and minimum indices of refraction exhibited by a large number of fragments. Where the orientation is known there can be no question about the vibration directions and indices in the fragments, and the method is free from the errors that pronounced cleavages are apt to introduce into the statistical method. We further believe that the use of fragments of known orientation usually requires no more time, but on the contrary generally saves time because one oriented section will give information obtainable only after the examination of a large number of unoriented fragments. For the student, the actual determination of a *specific* index of refraction gives him confidence in the accuracy of his work while the lack of a definiteness of purpose of a statistical method engenders uncertainty.

PHOSPHATIC CONCRETIONS NEAR JUNCTION CITY, KENTUCKY

RAYMOND EDMUNDSON, *Cornell University, Ithaca, New York.*

A recent paper on spherulitic concretions of dahllite[1] prompted the writer to examine some phosphatic concretions from the geology collection of Cornell University, which had been collected at the base of the New Providence shale (Mississippian), near Junction City, Kentucky.



(*a*) (*b*)

FIG. 1. (*a*) Polished cross section showing alternation of concentric light and dark bands; (*b*) External surface. Natural size.

MEGASCOPIC CHARACTERS

The shape of the phosphatic concretions resembles a thickened lens whose longest diameter averages about 4 cm. The color of the weathered surface is a light gray, except for small areas which are stained brown by iron oxide. Directly beneath the veneer of weathering and extending toward the center (Fig. 1*a*) are several alternating light and dark brown concentric rings. These color variations appear to be the result of an unequal distribution of limonite which formed from pyrite. A few minute unaltered crystals of pyrite may be seen on the polished surface.

The uniform texture of the weathered exterior (Fig. 1*b*) resembles the surface of an orange. In addition to this pitted surface, the concretions are distinctly marked by closely spaced parallel grooves which are related, probably, to the bedding in the enclosing rocks. The stratification may be traced, although poorly defined, across the polished surface.

MICROSCOPIC CHARACTERS

The concretions are composed principally of dahllite, with minor amounts of calcite and pyrite. In addition, it is possible that a part of

[1] McConnell, Ducan, Spherulitic concretions of dahllite from Ishawooa, Wyoming: *Am. Mineral.*, vol. **20**, pp. 693–698, 1935.

the groundmass may be amorphous calcium carbonate-phosphate, but since with increasing magnification more and more microcrystals are discernible, it appears reasonable to assume that the entire concretion is crystalline.

The dahllite occurs as aggregates of anhedral crystals with a maximum length estimated at .05 mm. Since the crystals forming the aggregates are poorly defined and extremely small, all of the optical properties could not be ascertained with certainty from thin sections. They were found to have moderate relief and in color varied from colorless to a pale brown. Crushed fragments were studied in more detail, and the indices, determined by the use of liquids, ranged between 1.615 and 1.624. These indices, although not representing the maximum range for dahllite, are significant for its identity. In addition, it effervesces in cold dilute acid, gives water in a closed tube, and yields chemical tests for phosphate and calcium.

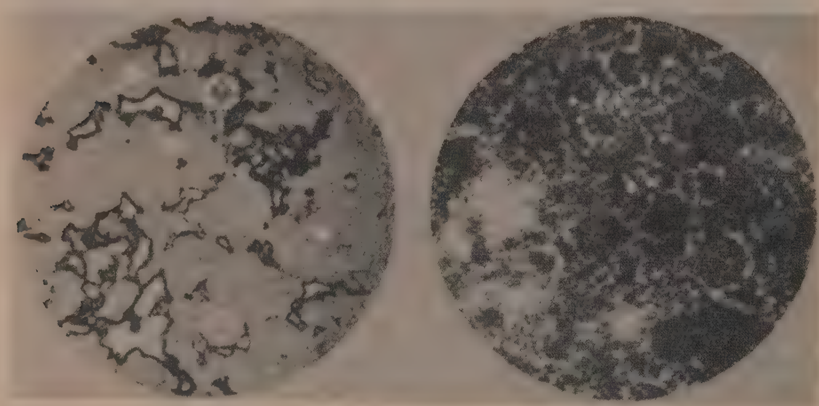


FIG. 2. FIG. 3.

FIG. 2. Photomicrograph (ordinary light) showing radiolaria, fine-grained groundmass, and irregular masses of calcite. Dark borders around calcite are iron oxide. $\times 26$

FIG. 3. Photomicrograph (crossed nicols) showing radiolaria replaced by dahllite. Note larger crystals of dahllite along borders of the fossils. Irregular white areas are calcite. $\times 42$

Calcite, comprising approximately 10 per cent, of the concretions, occurs as irregular bodies replacing the fine-grained groundmass of dahllite. An examination of polished surface and thin sections disclosed that small crystals of pyrite, most of which show alteration, were scattered through the dahllite and calcite.

The occurrence of abundant organic remains within the concretions is of special interest. These include well defined radiolaria and a few sponge spicules. With ordinary light (Fig. 2) only the larger radiolaria

are visible, but with crossed nicols (Fig. 3) most of the dahllite appears to have replaced the fossils. It is also noticeable that the larger crystals of dahllite are limited to the borders of the radiolaria.

Origin

According to Rogers and Kerr,[2] "Dahllite occurs as a secondary mineral in phosphorite or so-called phosphate rock. The usual associate is collophane. The dahllite has probably been formed by the gradual crystallization of the collophane and by the migration of some of the calcium phosphate."

Nothing is known regarding the field relations of these concretions, but conclusions based on this brief study suggest the possibility that the organic remains were replaced by collophane and the dahllite represents a recrystallization of the amorphous calcium carbonate-phosphate.

A RAPID MICROSCOPIC METHOD FOR DISTINGUISHING QUARTZ FROM UNTWINNED OLIGOCLASE-ANDESINE

Theodore A. Dodge, *Morococha, Peru.*

The distinction between quartz and untwinned oligoclase-andesine in thin section, or powder, is difficult to make, and is a problem not infrequently encountered in petrographical work. The concurrence of the indices of these two minerals makes their separation by means of index liquids impractical. The use of interference colors is untrustworthy. Interference figures, while capable of affording a qualitative answer, can in no way be relied upon to furnish even an approximate quantitative answer without hours of work, and where the number of grains is limited (as in a thin section), or where the grain size is very small, they are useless.

An obvious method for overcoming this difficulty, but one the rapidity and accuracy of which are not generally appreciated, is to be found in the universal stage. Quartz, because of its uniaxial character, when turned to extinction, remains so with a rotation in either the plane of the polarizer or that of the analyzer. Feldspar, being biaxial, in the general case does not. It is only necessary, therefore, to turn the unknown grain to extinction on the inner vertical axis of the universal stage and then make two rotations, one on the north-south horizontal axis, the other on the east-west horizontal axis. If with either of these rotations the grain stays at extinction, it is quartz; if not, it is feldspar.

Some feldspar grains behave like quartz due to a favorable orientation. The number in any given case depends for the most part on the accuracy

[2] Rogers, A. F., and Kerr, P. F., *Thin-Section Mineralogy:* McGraw-Hill, p. 194, **1933.**

of the instrument and the care used by the worker, although grain size may be a factor. Using this method the writer obtained in studying a thin section containing nothing but feldspar (identified by twinning) results indicating the presence of ninety per cent feldspar and ten per cent quartz. Greater care reduced this error to five per cent, but it was found that for ordinary work less care and the application of a ten per cent correction factor served the purpose better.

In the application of this method of distinguishing quartz and untwinned oligoclase-andesine the writer has in any one thin section tested from thirty to sixty grains, depending upon the relative proportions of quartz and feldspar present and the accuracy desired. The time required was from ten to thirty minutes.

No careful checks have been made on the accuracy of the results obtained, but the writer has felt justified in assuming an error of less than ten per cent, and careful work would undoubtedly reduce this considerably.

AGUILARITE FROM THE COMSTOCK LODE, VIRGINIA CITY, NEVADA

ROBERT R. COATS, *University of California, Berkeley, California.*

Examination of polished specimens of ores from the Comstock Lode has revealed the presence, hitherto unsuspected, of the silver sulphoselenide, aguilarite. Aguilarite was not recorded by E. S. Bastin[1] in the only previous paper on the ores of the Comstock Lode. It occurs in dark gray, sectile masses, intimately admixed with other minerals, and exhibiting a poor cleavage, visible only in hand specimens. It replaces base metal sulphides and calcite, and is replaced by argentite, electrum, and stephanite.

According to Schneiderhöhn and Ramdohr,[2] aguilarite is an isomorphous mixture of the naumannite and the argentite molecules, and is isometric above 133°C., probably rhombic at usual temperatures. The differences, due to inversion, may explain the variations in properties shown in the columns below. In the first column are listed the properties of aguilarite from the Comstock; in the second, the properties as recorded by Farnham[3]; and in the third column, those of aguilarite as given by Short.[4] In the fourth column those of naumannite are cited as given by

[1] Bastin, E. S., Bonanza ores of the Comstock Lode, Virginia City, Nevada: *Bull.* **735C,** *U. S. Geol. Survey*, 1922.

[2] Schneiderhöhn, H., and Ramdohr, P., *Lehrbuch der Erzmikroskopie*, 2 Band, Berlin, S. 272, **1930.**

[3] Farnham, C. M., *Determination of the Opaque Minerals*, New York. p. 21, **1931.**

[4] Short, M. N., *The Microscopic Determination of the Ore Minerals: Bull.* **825,** *U. S. Geol. Survey*, p. 86.

Schneiderhöhn and Ramdohr, the etching properties being taken from Murdoch.

Microchemical tests showed only the presence of silver, sulphur, and selenium. The amount of selenium was apparently variable, judging from the color of the residue resulting from solution in HNO_3, but this may have been due to the difficulty of securing samples free from contamination by argentite. The mineral does not differ sensibly from argentite in its etch reactions, except that it reacts more slowly with KCN, and shows grain boundaries, due to tarnishing in various shades of gray, after a minute or more. It polishes slightly better than argentite, and is isotropic, compared to argentite, or very weakly anisotropic.

	1 Coats *Aguilarite*	2 Farnham *Aguilarite*
Etch Reactions		
HNO_3	Negative	Slowly stains brown
HCl	Fumes etch slightly	Fumes slowly stain brown
KCN	Stains gray, brings out structure	Negative
$FeCl_3$	Stains iridescent	Stains gray
KOH	Negative	Negative
$HgCl_2$	Stains iridescent	Stains iridescent
Optical	Isotropic	Isotropic
Talmage hardness	B—(estimated)	A
Color	Gray, darker than argentite, slightly greenish	Gray-white, olive-green with galena
Cohesion	Sectile	Sectile
Light etching	Very slow	Not given

	3 Short *Aguilarite*	4 Schneiderhöhn-Ramdohr *Naumannite*
Etch Reactions		
HNO_3	Slowly stains brown	Effervesces, surface roughened
HCl	Negative or slight tarnish	Light brown stain
KCN	Negative	Negative
$FeCl_3$	Tarnish iridescent or stains light brown	Light brown stain
KOH	Negative	Negative
$HgCl_2$	Stains iridescent	Not given
Optical	Isotropic (also anisotropic)	Plainly anisotropic
Talmage hardness	A	B
Color	Gray	White
Cohesion	Sectile	Not given; said to have (100) cleavage
Light etching	Not given	Not given

It should be noted that the determination of Farnham was made, as far as can be judged, on the original aguilarite from Guanajuato, Mexico, as described by Genth,[5] who found the mineral to be sectile, malleable, and of variable composition. At Guanajuato, as on the Comstock Lode, the mineral is associated with argentite and silver, and is replaced by stephanite.

The malleability of the mineral is probably responsible for the failure of earlier workers to distinguish it from the associated argentite.

[5] Genth, F. A., Contributions to Mineralogy: *Am. Jour. Sci.*, vol. **141**, p. 401, 1891. Genth, F. A., Contributions to Mineralogy: *Am. Jour. Sci.*, vol. **144**, p. 381, 1892.

BOOK REVIEWS

KLOCKMANN'S LEHRBUCH DER MINERALOGIE. Eleventh Edition, revised by P. RAMDOHR. Octavo XII+625 pages, with 613 illustrations. Ferdinand Enke, Stuttgart, **1936.**

This standard German mineralogy has served as a valuable reference work for nearly forty years for students of and workers in the science. Since 1912, however, it has undergone but few changes. In this revision, which was made by Professor Paul Ramdohr of the University of Berlin, the text has been completely rewritten and brought up to date.

In the main, the arrangement of the Eleventh Edition adheres rather closely to that of the earlier ones. Following a brief, introductory chapter of four pages, the book is divided into two parts: Part One, General Mineralogy, and Part Two, Special or Descriptive Mineralogy. In Part One, crystal forms, the internal structure of crystals and methods of investigation, general physical properties, chemical mineralogy and crystallography, formation of minerals, ore deposits, paragenesis, and the technical and industrial uses of minerals are discussed. It is in this portion of the book that the many changes which have been made are most noticeable. In Part Two, minerals are arranged according to the admirable Groth-Mieleitner classification. Although the descriptions are, in general, relatively brief, they appear to be quite adequate.

The revision has been carried out effectively by Professor Ramdohr, and in its present form Klockmann's "Mineralogie" will undoubtedly prove to be as popular as were the earlier editions.

EDWARD H. KRAUS

J. C. POGGENDORFF'S BIOGRAPHISCH-LITERARISCHES HANDWÖRTERBUCH FÜR MATHEMATIK, ASTRONOMIE, PHYSIK MIT GEOPHYSIK, CHEMIE, KRISTALLOGRAPHIE UND VERWANDTE WISSENSGEBIETE. Band VI: 1923–1931. Part 1 (A–E), 696 pages. Verlag Chemie, G.M.B.H., *Berlin*, **1936.** Price for each part is RM 85, in paper cover; when ordered in advance RM 76.50.

This exceedingly comprehensive Manual contains complete data relative to the life and works of scientists in the numerous fields listed above. Volume 6 deals with the period covering 1923–31. It will appear in four parts of which Part 1 (A–E) is now available. Part 2 (F–K) is in print and will be published this fall; Part 3 (L–R) and Part 4 (S–Z) are in preparation and will be printed in the summers of 1937 and 1938, respectively.

Some idea of this vast undertaking can be obtained from the statement that over 3500 periodicals are being abstracted in the preparation of this Handwörterbuch and when completed it will contain references to 8000 scientists of all nations. As an accurate and complete reference work this Manual is indispensable.

W. F. H.

PROCEEDINGS OF SOCIETIES

MINERALOGICAL SOCIETY OF AMERICA

It is planned to hold the seventeenth annual meeting of the Mineralogical Society of America, December 28th to 30th, at Cincinnati, Ohio. Arrangements are being made by the local committee in Cincinnati to care for members of the Society. Further information regarding the meeting will be mailed to the members of the Society about October first.

PAUL F. KERR, *Secretary*

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Science of Philadelphia, May 7, 1936

Mr. H. W. Arndt presided at a stated meeting of the Philadelphia Mineralogical Society, 39 members and 51 visitors being present.

Mr. Richmond E. Myers of Bethlehem, Pa., addressed the society on "Minerals and Mineral Collecting in Norway and Spitzbergen," giving a detailed description of his experiences on several trips to these famous mining and mineral regions. Motion pictures and specimens illustrated the talk.

Albert Jehle exhibited green and blue vivianite crystals from Mullica Hill, N.J., also pyrite, brown garnet, rhodonite, red and green willemite and graphite from Franklin Furnace, N.J. Mr. Myers stated that the Midtown-Manhatten tunnel dumps were being taken to Long Branch and dumped in the Ocean. Barges tied up near the railroad station are accessible to mineral collectors. E. H. Cienkowski reported that the machinery was being removed from Moores Station quarry, but Lambertville trap rock quarry is working. He found traces of apophyllite at Stockton quarry; limonite pseudomorph after pyrite 1″ in each dimension and limonite geodes at Oreland, Pa., also hematite plentiful at Edge Hill, Pa.

W. H. Flack, *Secretary*

NEW YORK MINERALOGICAL CLUB

American Museum of Natural History, New York City, May 20, 1936

President B. T. Butler presided at a stated meeting with 77 members and guests present. In the business meeting it was decided to assemble all of the available data from the past history of the club, in anticipation of the fiftieth anniversary celebration next fall.

The first speaker of the evening was F. H. Pough, who spoke on "Crystallographic Notes on Powellite and Augelite." He described some of the investigations being carried on at the American Museum, showing drawings of crystals of these minerals with some new forms. The new forms on powellite were: 113 (previously observed only on artificial crystals), 137, 317, 319, 123, 213, and 323, all on crystals from Tonopah, Nevada, and 131 on a crystal from the old Michigan locality. Augelite crystals from Mono Co., Cal., were shown, on which the following new forms were discovered: 130, 210, 310, 510, 104, 114, 113, 334, 111, 221, 331, and $\bar{1}21$. Unusual features on 001 and $\bar{1}01$ were shown in photomicrographs of etch pits and accessories on these forms. New angle-tables for use with the two-circle goniometer for both of these minerals were shown; with changed elements and new angles as had been shown to be necessary in the case of powellite.

The second speaker of the evening was Dr. A. C. Hawkins, who addressed the club upon "Mineral Collecting in Georgia." Dr. Hawkins has recently returned from work in this region, in the course of which he was able to visit many mineral localities. Among his more interesting finds were zoisite from the vicinity of Stone Mt., hyalite from the same region, collected after dark with the aid of a portable ultra-violet light projector, differentially coated quartz crystals from La Grange, kaolin from Macon, and staurolite, talc and marble from near Fanning. The talk was illustrated with lantern slides of some of the localities and a series of views of the Birmingham, Alabama, iron mines.

F. H. Pough, *Secretary*